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FUNCTIONAL DESIGN FOR OPERATIONAL EARTH RESOURCES GROUND DATA PROCESSING

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FINAL REPORT

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Prepared by
Earth Resources Technology Office
Applied Technology Laboratory
Houston Operations

TRW
SYSTEMS

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This report documents the completion of effort under contract NAS9-12336, "Space Station Experiment Data Ground Processing Study". This report, in conjunction with the Mid-Term Report, "Design Requirements for Operational Earth Resources Ground Data Processing", 12 May 1972, describes all work performed in the contract period 12/6/71 to 9/6/72. NASA/MSC contract Technical Monitor is G. R. Kimball (FS52), Flight Support Division, MSC.

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1.0 INTRODUCTION

In July of this year NASA successfully launched the first Earth Resources Technology Satellite (ERTS A). Early images from the ERTS Multispectral Scanner (MSS) indicate that the data will have an applications utility considerably beyond that anticipated. The quality of the MSS data, coupled with the repetitive and synoptic nature of its coverage, make it an excellent precursor to any subsequent manned or automated platform intended to routinely provide data to operational users. The ERTS experiment, in conjunction with experiments flown on Apollo, those planned for Skylab, and the ongoing NASA aircraft remote sensing experience, are pointing the way towards genuine utility of earth survey data.

The departure point for this study was the assumption that the current experimental activity in remote sensing does, in fact, evolve into an environment of beneficial and routine use of the data. This evolution is assumed to be well underway by the late seventies and nearing completion as the Space Shuttle becomes a useful tool for earth observations. The main thrust of the study has been to define the requirements of the would-be operational users and to address the fundamental question, what is the nature of the processing systems required to convert remotely sensed data to useful information?

2.0 SUMMARY AND CONCLUSIONS

This report documents the conclusion of a nine month study addressing the ground data processing of remotely acquired earth survey data. The primary goal has been to define a conceptual approach to the design of a processing system(s) which would evolve early in the post-Skylab period and extend well into the Space Shuttle era. A dominant theme of the study has been to define processing requirements of various user agencies in the context of operational management programs utilizing and depending upon the acquired data. The study assumes that there is continued need for, and benefit from, experimental research and development efforts, but that the principal contribution of remote sensing technology should be in supporting operational activities of agencies with well established jobs to perform. The difficult task then becomes one of quantifying the volume and nature of data to be processed and the techniques to be employed to generate useful information for these operational users.

Study emphasis has been on developing a "unified" concept for the required ground system(s), capable of handling data from all viable acquisition platforms and sensor groupings envisaged as supporting operational earth survey programs. The platforms considered include both manned and unmanned spacecraft in near earth orbit, and continued use of low and high altitude aircraft. The sensor systems include both imaging and non-imaging devices, operated both passively and actively, from the ultraviolet to the microwave regions of the electromagnetic spectrum.

Motivation for performing the current study was provided by consideration of the following problems:

- first - in the area of manned systems, the post-Skylab "experiment" data processing is loosely defined
- second - in spite of considerable interest and activity on the part of would-be users of earth survey data, the requirements for data supporting operational activity are poorly identified and rarely quantified

third - automated and man-assisted techniques for converting remotely sensed data to information are primarily topics of research (this situation essentially explains the existence of the first two problems)

fourth - design and development of a "unified" ground processing system for operational programs requires lead time of approximately 3 to 5 years

fifth - evaluation tools do not exist to rapidly assess the impact on ground systems of evolving processing requirements for earth resources data

Specific study objectives derived from the above motivation are:

- survey, catalog, and analyze output data characteristics of sensors expected to be flight qualified in the time frame of interest
- define preprocessing requirements generally attributed to unique characteristics or anomalies associated with the sensors of concern
- structure a method for defining realistic operational user requirements for various remotely sensed data products
- relate required data products to a set of modular processing functions to be performed by the ground system (onboard processing is considered only as it may impact the ground workload)
- relate the set of modular processing functions to equipment types by which implementation of the functions may be obtained (equipment types considered include off-the-shelf and anticipated devices based on digital, electronic analog, photo-optical, and electro-optical principles)
- develop a method for synthesizing candidate ground processing systems
- develop a simulation tool to evaluate competing candidate systems
- select promising concept(s)

In performing the overall study, effort has been devoted to six major task areas: user requirements; sensor systems, processing requirements, techniques, and equipment, onboard processing implications, system performance simulation, and system synthesis and conceptual design. The first four of these areas are reported in detail in the contract Mid-Term Report, "Design Requirements for Operational Earth Resources Ground Data Processing," 12 May 1972. The current report concentrates primarily on summarizing the users' requirements for data products, defining requirements for system design, synthesizing a conceptual system approach and developing a System Performance Simulation. The interrelation of the study objectives and the major task areas is shown in Figure 2-1.

Overall study conclusions are summarized below by major areas of concern.

USER REQUIREMENTS

Conclusion 1 - Meaningful requirements for remotely sensed data can best be obtained by concentrating on a user community comprised initially of non-NASA, federal agencies (e.g., USGS, USDA, EPA, NOAA, etc.) as opposed to a lower tier of would-be users (i e., the "man-in-the-street," or the individual research investigator). This conclusion follows principally from the study's preoccupation with operational utility, which in turn dictated synthesis of management programs representing a charter for servicing, monitoring, controlling or providing a product to some area of socio-economic activity. The issue then becomes one of substituting remotely acquired data for current conventional sources of data, or augmenting the conventional information by the additional use of remotely sensed data.

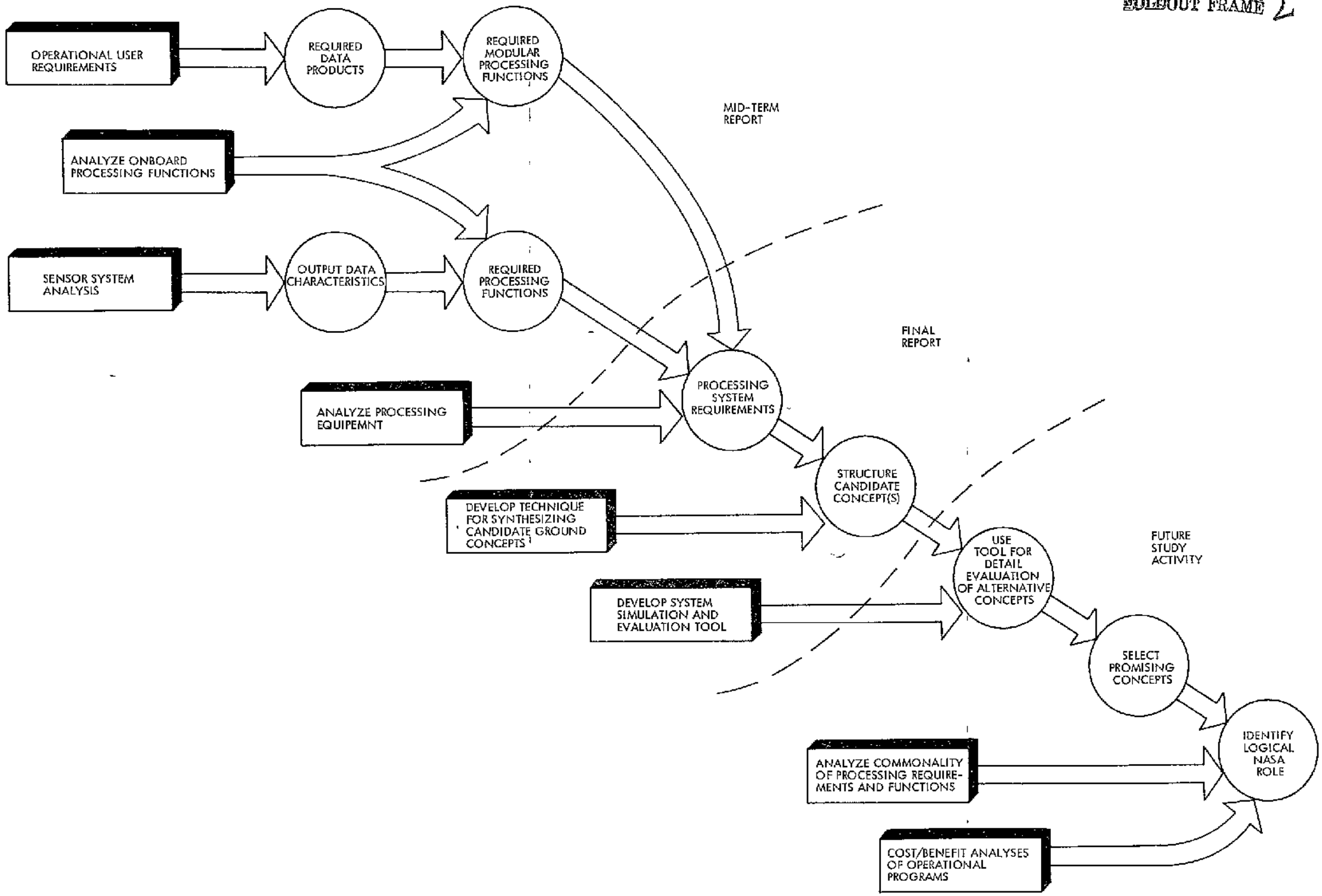

Figure 2-1. Study Flow and Objectives

Conclusion 2 - In analyzing a number of postulated operational management programs, it is concluded that the number of uniquely different data products (those things that the ground processing systems must produce) that agencies can effectively use in their various decision making and management functions is relatively small (i.e., less than twenty). The small size of this family of data products is significant in determining the degree of "service" oriented processing that a single agency might perform for others.

Conclusion 3 - The predominance of requirements for data products by the management programs considered can be simultaneously satisfied by input imagery data characterized by, approximately weekly coverage of the continental United States, with an effective ground resolution approaching 50 feet, with four to six spectral bands through the visible to the near infrared wavelengths.

SENSOR SYSTEMS

Conclusion 1 - Spatial resolution ranging between 50 and 100 feet is obtainable from ERTS altitude ($\sim$500 n. mi.) in the 1975-85 time frame. Implications of this high resolution will be longer optics focal length, larger focal plane format (assuming approximately 100 n. mi. swath width is maintained), and heavier instruments.

Conclusion 2 - Multispectral imagers can best be implemented with the solid state array "push broom" technique to eliminate mechanical movement of optical components with a resultant step towards long term reliability.

Conclusion 3 - Framing photographic cameras will continue to have utility through the next 5 years but will eventually be phased out of operational systems as electronic scanners approach the necessary spatial resolution.

PLATFORMS

Conclusion 1 - The circular, polar, 500 n. mi. sun-synchronous orbit of ERTS inherently provides near ideal coverage potential for operational missions (particularly if more than one spacecraft is phased within this orbit to give repetitive frequency below 18 days). The implication of this desired orbit coupled with the expected payload weight of the required platforms (i.e., well in excess of the 2,000 lb ERTS class payload) will dictate the use of the Space Shuttle as the launch vehicle for both automated and manned earth survey platforms (the latter possibly being a manned laboratory on the shuttle orbiter eventually evolving to a fully modular space station).

Conclusion 2 - The Space Shuttle may find its greatest role in earth resources in operational maintenance and replacement of the automated systems needed for sustained, long term data acquisition.

Conclusion 3 - The most promising aspect of a manned orbiting earth resources platform is the role that man might play in selective data acquisition and screening, and decision verification supporting ground based analysts. This latter role supposes that the onboard analyst might have access to higher quality imagery (e g., photo quality processing) and therefore be able to confirm things in the imagery that the ground analysts only suspect.

Conclusion 4 - Aircraft will see continued usage into an operational era, both as a source of "ground truth" data and as an acquisition platform which can be flexibly and selectably deployed.

DATA PROCESSING TECHNIQUES

Conclusion 1 - Machine-assisted classification of ground objects based on spectral information content promises to reduce the manual interpretation time currently required to analyze and process imagery.

Conclusion 2 - Spectral signature classification techniques will continue to have a high degree of dependence on "training" site ground truth information and are therefore inherently "adaptive" in nature. The real issue is whether or not the adaptive processes can be highly automated or whether they continue to require the assistance of men for the adaptive training.

Conclusion 3 - There are a number of viable data products required by users that do not depend upon the eventual success of automatic classification schemes (e.g., photomaps, overlays, thematic maps, statistical summaries, change discrimination, etc.). This is a significant point in that there is technical risk associated with the current approaches to automatic classification based solely on spectral content (man as a classifier uses a subtle combination of several types of information content within an image, e g., spatial relationships, tonal properties, textural characteristics, etc.). The implication of this conclusion, being, that in the worst case if automatic techniques did not mature, it is still possible that cost-effective applications exist. This latter contention is further reinforced by the estimate of the total data volume to be processed to satisfy user agencies, the lack of urgency to process it and the recognition that it is not totally unreasonable to rely heavily on trained, human interpreters to handle the operational workload.

Conclusion 4 - Removal of both geometric and radiometric distortion from imagery can best be performed by utilizing ground scene reference targets as opposed to mathematically modeling the individual error sources and then inverting these models to correct the imagery This would take the form of well surveyed ground control points for geometric corrections (currently employed by the ERTS processing facility at GSFC), and some type of calibrated, intense light source on the ground for radiometric corrections.

PROCESSING HARDWARE

Conclusion 1 - The flexibility of digital image processing makes it the leading alternative for most forms of processing. The necessary throughput speed required will most probably be obtained by specialized, solid state digital modules with a high degree of parallel execution This type of digital implementation is also the leading candidate for both aircraft and spacecraft onboard processing

Conclusion 2 - Both optical processing (Fourier transformation and spatial frequency filtering) and electronic analog computing currently show limited potential for consideration in operational ground systems

Conclusion 3 - Ground processing systems will have a continued, long term dependence on certain aspects of high quality photo processing. This will probably remain true even if photographic cameras are eventually phased out as primary sensors. This conclusion could be negated, however, by a significant improvement in either electron or laser beam film recorders with self contained "developing" and copying capability.

TOTAL GROUND SYSTEM

Conclusion 1 - The limited size of the family of required data products tends to promote the idea of a single agency providing those products to the user agencies as a service.

Conclusion 2 - The number and geographical distributon of these self contained "service processing centers" should be based on efficiency and convenience of interface with the users.

Conclusion 3 - A "unified" system which handles data from a variety of data platforms and sensor types appears technically feasible.

Conclusion 4 - Distribution of data products from the service centers to the user agencies can be through normal mail or courier services (i.e., on the order of one to three days response).

GENERAL

Conclusion - NASA must advocate and promote the use of remotely acquired data for operational utility Many problems remain concerning details of operational procedures and techniques and these can best be solved by NASA helping to demonstrate the operational benefits of the earth survey program. This contention is in recognition of the communication gap that normally exists between application specialists (i.e., agriculturists, foresters, etc.) and the NASA technology specialists; and the observation that many agencies need to be shown more than just the spark of an application idea stemming from a principal investigator's research. Instead, the agencies need to be shown the complete system costs of going operational, in order that these may be measured against the expected benefits In short, the technology does not appear to be the limiting factor, but rather the details associated with an operational system

3 0 REQUIRED DATA PRODUCTS

This section contains a summary description of the data products that are commonly required by interpreters and analysts engaged in the earth sciences. The detailed management functions from which this summary is derived are included in the Mid-Term Report.

3 1 User Requirements Analysis

The prime interest throughout this study was to develop an understanding of the requirements imposed upon the ground data handling system by operational resource management programs Therefore, considerable attention was given to the current activities of Federal agencies charged with the management of natural resources, and the information needs of these agencies not currently satisfied by conventional data sources.

There is a marked lack of information which definitively outlines the requirements of the agencies for remotely sensed data. This is understandable since this technology is viewed as offering promise in several areas, but commitments to operational utility must await validation through experience with ERTS, EREP and aircraft data. Furthermore, it must be noted that until considerable sophistication is developed, statements of requirements will reflect management needs (e.g., assessment of the acreage of a particular crop) and probably contain little information concerning basic data requirements (e.g., resolution) or processing (e.g., geometric corrections).

An analytical framework was needed which would allow the study to push ahead by working around the lack of defined requirements. The basic requirements of this framework were:

- It should bound the requirements for data products
- It should facilitate ready evaluation of processing requirements accruable to specific stated requirements

The basic technique developed in the study is outlined Figure 3-1

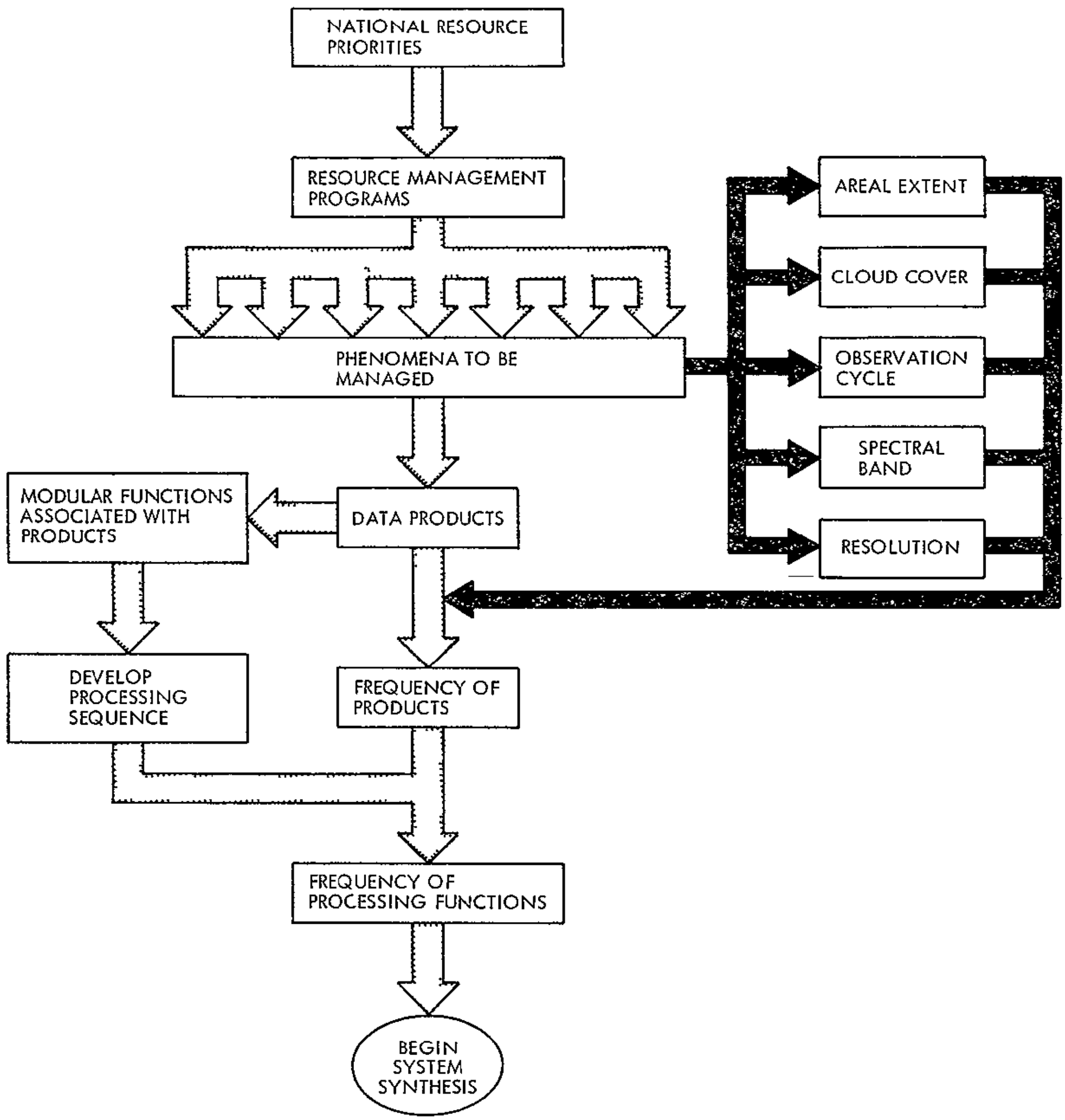

Figure 3-1. User Requirements Methodology

The potential applications for remote sensing technology which were selected for evaluation were all concerned with the management aspects of natural resources, these applications were deemed to be potentially feasible based upon successful research efforts and projected state-of-the-art for remote sensing technology. The applications were organized into the following programs·

- Hydrological Resources Management
- Geological Resources Management
- Agricultural Resources Management
- Forestry and Rangeland Resources Management
- Coastal Zone Management
- Urban Dynamics Management
- Environmental Resources Management

The large number of management functions contained in these synthetic programs are described in the Mid-Term Report of this study with respect to requirements for

- Resolution
- Frequency of Observation
- Swath
- Spectral Region
- Sophistication of Processing
- Areal Extent

In addition, preliminary assessments of data products for the program are provided in the Mid-Term Report. The remainder of this section will be devoted to general observations about the programs considered, as related to the feasibility of defining a minimum set of required data products.

There is a large number of applications for which observation frequencies on the order of one to two weeks (i.e., one or two spacecraft in ERTS-like orbits) are entirely satisfactory. However, the operational utility of ERTS data is severly hampered by the available resolution. The technology for increased resolution is available, but operational utility will require considerable work in tradeoffs of payloads and platforms. The fact that operational utility of the data is "enticingly near" suggests that attention

must be given to developing econometrically sound applications programs. This will likely require development of a system for a multiplicity of management applications. It is unlikely that the applications will group into the rather "clean" management programs of the Mid-Term Report, rather, a single system will support elements selected from those programs. The foregoing argument is further manifested in material presented in the Mid-Term Report relating to commonality of requirements among various management functions.

3.2 Data Products

The earth sciences are largely non-mathematical and to some extent empirical in nature Considerable emphasis is placed upon the intuitive and subjective processes of a trained analyst or interpreter. The classical discipline of photogrammetry, which borders on being an art form, provides the basis for much of the interpretive work in earth resources Figure 3-2 describes some of the more frequent analytical modes employed by imagery interpreters. The various aids or presentation types most commonly used are shown for the various modes. There are undoubtedly unlimited variations on these analytical modes due to the inherently subjective nature of the analysis processes, however, it is believed that the number of useful aids to interpretation, as well as the media of presentation, are relatively limited.

The remainder of the section describes a set of these interpretive aids or data products. An attempt was made to define the smallest set of products commensurate with satisfying a majority of the projected analytical needs. The following is a list of these data products grouped according to output media:

- Photographic
  - Photomaps
  - Prints
  - Transparencies (including overlays)
- Plotted
  - Thematic Maps
  - Statistical

ANALYTICAL MODE	INTERPRETATIVE AID
IMAGERY IS USED REPEATEDLY FOR PLANNING CONSTRUCTION, ASSIGNING WORK CREW, ETC	PHOTOMAP
IMAGERY IS USED TO SUPPORT VISUAL CHANGE DISCRIMINATION. COMPARISON BASE MAY BE MAPS OR OTHER IMAGERY.	OVERLAYS (TRANPAR-ENCIES OR ADJUSTED SCALE PRINTS)
IMAGERY IS USED IN PHOTOGRAMMETRIC PRO-CESSES FOR MAPPING OR TO MONITOR RATE OF MOVEMENT	GEOMETRICALLY REFER-ENCED SPATIAL MEASUREMENTS
APPLICATION IS CONCERNED PRIMARILY WITH INSTANTANEOUS SPECTRAL OR TONAL QUALITIES	GEOMETRICALLY REFER-ENCED SPATIAL MEASUREMENTS
IMAGERY PROVIDES SOURCE OF DATA TO SUP-PORT PREDICTION OF FUTURE STATES. TRANSFORMATION OF DATA TO COMPATIBLE UNITS AND CALIBRATION/CORRELATION WITH OTHER DATA MAY BE REQUIRED	INPUT FOR MATHEMATICAL MODELS
APPLICATION REQUIRES VISUAL ASSOCIA-TION OF METRIC DATA DERIVED FROM IMAGERY WITH OTHER DATA TYPES	THEMATIC MAPS
INFORMATION CONTENT IS CONTAINED IN OVERALL TRENDS AND PROPERTIES OF THE ENSEMBLE OF METRIC DATA OF THE IMAGERY	STATISTICAL SUMMARIES
INFORMATION CONTENT IS IN CHANGES FROM A GIVEN BASE SUBTLETY OF CHANGES OR DATA VOLUME DICTATES AUTOMATED PROCEDURES	AUTOMATIC REPORT OF CHANGES
APPLICATION REQUIRES ASSESSMENT OF AREA/ EXTENT OF IMAGED REGION OF SPECIFIC PROPERTIES	AUTOMATED INVENTORY

Figure 3-2. Analytical Modes

- Recorded

  Spectral Measurements of Photographic Imagery
  X-Y Locations of Features in Imagery
  High Density Digital Tapes
  Computer Compatible Tapes (including possible inputs to mathematical models)
  Specialized Program Tapes

- Tabulated

  Inventory Summaries (includes change discrimination as a special case)
  Statistical Data Summaries
  Production Summaries

These products are discussed in more detail below; the primary emphasis in the following material is in describing the attributes of the various products which determine the specifications for processing for specific users

Photographic Products - The earth sciences depend heavily upon photographic products to serve both as a direct source of information and as an interpretative aid in understanding other measurements.

Prints and transparencies can be derived from film exposed in the onboard optical train or film exposed according to characteristics of electronic signals. This latter category could include exposure in accordance with the results of sophisticated classification schemes (e.g., "color corn yellow"). These products may require spectral slicing in which the film is exposed to a selected spectral range, or accordingly color composites may be required in which the various color layers are exposed using successive, registered frames representing individual spectral ranges. Special cases may require adjustment of tone and contrast. The overlay tools are transparencies. The attributes which must be specified by a user of photographic products are·

- Emulsion
- Positive or Negative
- Instructions for Tone and Contrast
- Colors for False Color Assignment
- Geometric Fidelity
- Photometric Corrections
- Transparency or Print
- Any Cropping Bounds
- Principal Point
- Any Registration Base
- Scale

Photomaps are maplike products which are based upon photography. All of the above photographic attributes are required for specification including instructions for

- Gridding
- Annotation

Plotted Products - The earth sciences use plotted products to better understand data and to provide the basis for visual correlation of imagery with other knowledge.

The term "thematic maps" is commonly used to describe two data products:

- Extracted themes (e.g., soil) displayed on an appropriate grid
- Plots of summarized data presented on maps or photographs

The first category is actually a photomap described earlier, and throughout this report "thematic map" will refer to the latter category.

The information which is summarized can be based upon imagery data. For example, isopleths could be plotted on a map connecting points of like spectral response from a given channel. Also, the information to be summarized could be obtained from other sources and displayed on imagery.

For example, isopleths of temperature readings collected in an estuary at the time of an underflight (conceivably, an agency requiring such a product could be required to maintain the data base of external data) could be plotted. A variety of statistical routines are required to support a general thematic mapping capability, with the variation from a normal statistical capability being the ability to display the results of a "moving window", i.e., the statistical properties of data points lying within a square defined by corner ticks throughout the imagery. Several presentations are normally used including pie plots, post plots, vectors and contours. The media upon which the information is plotted may include paper, acetate (for overlays) and photographic prints. The attributes which must be specified for these products include:

- Data to be summarized
- Plotting base
- Summary to be made
- Form of presentation
- Media
- Coordinate frame of data
- Coordinate frame of plotting base

Statistical plots may be required to provide insight into the properties of raw data and data which has been grouped with a classification scheme. To fully specify these plots (normally histograms and scatter diagrams) the following information must be provided

- The space to be plotted
- Ranges for histograms

Recorded Products - Some agencies will hve capabilities for computer analysis of imagery data. The ground data handling system would provide computer tapes to be used by these facilities.

Precision spectral measurement of products could result from the use of standard densitometric and colorimetric techniques using either electronic or photographic film as the basic data Such a data product might be required if applications are developed which determine physiological/physical parameters as directly functional to emulsion response.

Attributes would include:

- Spectral range of interest
- Grid distribution of measurements
- User computer tape requirements

X-Y locations of features in imagery are included to account for support to applications requiring photogrammetric processes. These measurements could be used to monitor the movement of features (e.g., ice flows) or in mapping

Attributes include:

- Features of interest
- Desired precision
- Desired reference frame

High density tapes may be required for either raw data or data processed for certain corrections.

Attributes include.

- Level of radiometric and geometric fidelity
- User equipment requirements
- Requirement for supporting data

Computer compatible tapes would have these same attributes.

Special program tapes are included as a product based upon an assumption of the capabilities of the processing facility(ies). It would appear to be safe to assume that a facility would have available a multiplicity of digital computer algorithms which can be linked together in a flexible fashion. Furthermore, it may be assumed that there will be user agencies with computer capabilities to be used in the analysis of data. Conceivably, a service facility could develop a computer program tape which has the the necessary algorithms properly sequenced to serve the needs of the user agency The information required to specify this product includes:

- The specific requirements for processing
- The raw data
- The user agency equipment

Tabulated Products - User agencies may require computer printouts of analysis results and possibly some form of transaction summary. Inventory summaries would result from the use of classification schemes, but additional information might be required. This information could include total area for each category or individual areas described by center location, areal extent and classification Requirements for specification would include:

- Categories to be identified
- Location accuracy
- Accuracy of areal calculations
- Specific form of output

Statistical data summaries would utilize standard statistical algorithms. Specification requirements would include.

- Parameters to be summarized
- Statistics to be used
- Output format

Production summaries or cataloges would include description of data received, quality of data, corrections effected on data, products generated, and disposition of raw data.

Figure 3-3 illustrates the above family of data products and the respective media options.

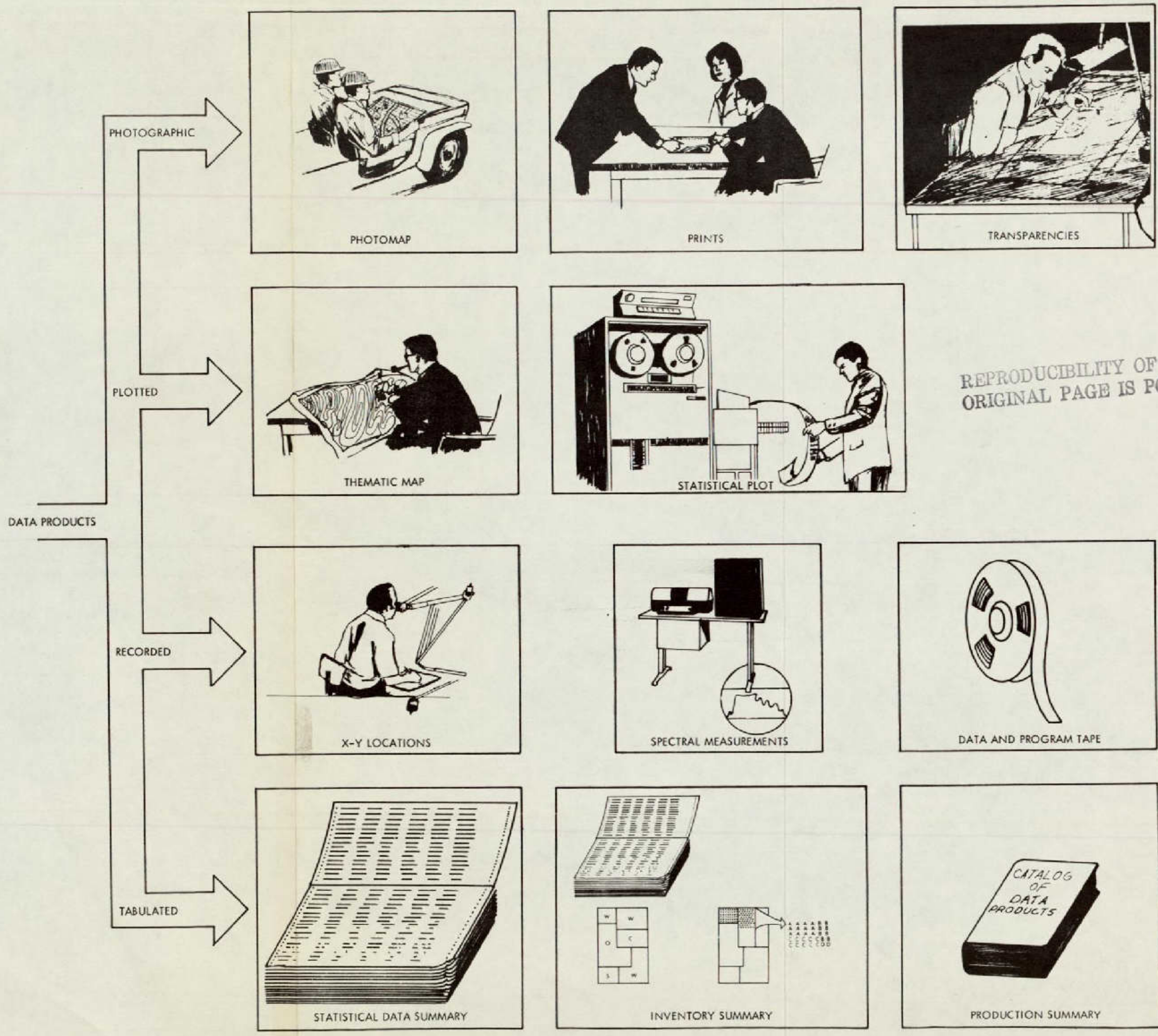

Figure 3-3. Data Products Family

Operational Utility - The processing systems' primary function would be to routinely produce data products for a user agency(ies) that has a specific chartered job to perform (i e., a federal agency which must monitor, control, or provide a service or product for some area of socio-economic concern), and who needs the data products to assist with management and planning functions associated with this job. Implied within this objective is the requirement to design a system with a throughput capability which is derived from a basic concern of the user agencies timeliness and response requirements. Additionally, the dedication to operational support inherently implies that the overall system operation will be cost-effective when compared to alternative or conventional methods of accomplishing the users' management functions (Note. The issue of cost-effectiveness or cost/benefits is outside the scope of the current study but it was the intent of this study to lay the foundation for subsequent analysis of costs and benefits to the would-be user agencies).

Interagency Compatibility - The question of geographical distribution and NASA/non-NASA management of ground data processing facilities will ultimately be resolved by consideration of many factors, both technical and non-technical. One objective, however, would clearly be to build in systems compatibility between any NASA processing facilities and those of other agencies being serviced or supported. This objective should go beyond simply input/output format and media compatibility to include transferability of software programs and modular processing components.

Growth and Flexibility - This objective can best be stated as the requirement for a truly modular system in which both software routines and processing logic modules (both analog and digital) and equipment types are easily replaceable or expandable with minimum impact to the overall system structure.

4.2 Functional Requirements

Consideration of the above objectives, and extrapolation from current experience being obtained at MSC and GSFC leads to the following functional design requirements:

- Input Flexibility - the system will be required to accept imagery data in various formats and media (e g , digital/analog tapes, film transparencies, etc) and to reformat and convert this data to any other usable media or format (e.g , computer compatible tapes) at any desired point within the overall processing stream.

- Correction and Calibration - the system must employ workable and practical correction techniques to remove distortion from the source data. A prime example is the current difficulty of successfully modeling all of the major sources of geometric distortion and geodetic positional error in the ERTS MSS and RBV data, and the practical alternative that was adopted by GSFC in the use of ground control points for geometric correction.

- Adaptive Correction - provision should be made for selecting the degree of geometric and radiometric correction necessary based on initial trials with the spectral recognition and classification processing subsystems (necessary only in those cases for which recognition and classification are a necessary step to arrive at a desired data product).

- Multistage Correlation - the system will be required to correlate and register image data sets which are acquired by the same platform at different times (temporal registration), different platforms at the same times (scale, frame size and central point differences) and different platforms at different times. This registration could be considered to approach a worst case problem when low altitude, high resolution aircraft photographic imagery taken at a given time is to be used in conjunction with high altitude ($\sim$ 500 n. mi.) satellite multispectral scanner data of low resolution acquired at a different time.

- Adaptive Classification - techniques for signature recognition and classification of ground objects based on spectral information content currently show a strong dependence upon ground truth or training sites for adaptive adjustment of the various algorithms and logic employed; the real issue being the feasibility of automatically providing the adaptive feedback versus continued use of man-in-the-loop as an on-line analyst for purposes of adaptation. A system requirement is the provision for this adaptive training cycle; irrespective of how it is eventually implemented.

- Manned Interface - for the training function described above, and for other purposes of monitoring, screening control, and interpretation, there exists requirements for information display to a human operator situated in both an on-line (typically interacting with digital or analog computational subsystems) and an off-line mode (i.e., interpreter at an optical projection viewer).
- Limited Data Management - a requirement exists primarily for short term data storage and retrieval for the purposes of calibrating and correcting subsequent data processing. Stated in this way the above implies. first, that data retention for the purposes of change discrimination (i.e., detection of change in the state of a ground scene of interest over a specified time period) would primarily be the responsibility of the ultimate user agency and as such is not considered an "output product" of the processing system; second, data retention and cataloging for the purposes of centralized archiving and general dissemination to the public will continue to best be performed in a functionally separate facility (e.g., the USGS/EROS Sioux Falls Data Center).
- Data Product Diversity - the processing system will be required to facilitate the generation of viable data products at many intermediate levels of data processing. This requirement is in recognition that many useful products exist that require limited processing or correction short of that possible by the system. An example would be producing an image copy in a single or composite spectral band for which no stringent radiometric corrections were required (e.g., a product intended for a photo interpreter interested in manually measuring the areal extent of a known and easily recognizable ground class).

4.3 Processing Alternatives

The best current example of a capability to produce remotely acquired imagery is represented by the NASA Earth Resources Technology Satellite (ERTS) launched July 24, 1972. This platform can produce over 9,000 separate images within a weeks time, each representing a ground scene 100 n. mi. by 100 n mi. A single spectral band and its associated frame of Multispectral Scanner (MSS) imagery represents over 50 million bits of data ($\sim$ 7.5 million picture elements/frame at an 7 bit encoding level).

The MSS total output data rate (for 4 spectral bands) is approximately 7 M bits/sec, and this one instrument is capable of operating essentially continuously with an expected lifetime of over one year

The message implied in a high data rate capability such as the experimental ERTS would appear to be:

First: any future platform evolving from the ERTS experience intended for operational utility will desirably employ highly selective data acquisition methods (i.e., turn the sensors off periodically based on intelligent guidelines stemming from a consideration of how much data can effectively be converted to information required by user agencies).

Second: given that an acquisition platform can be controlled to collect only operationally meaningful data, it is highly probable that the remaining data volume and transmission rates will be sufficiently large to dictate all possible efficiency in achieving the necessary ground system throughput and responsiveness.

In responding to the concern for high system throughput, the basic dilemma that arises in selecting a processing approach is that of digital image processing versus some form of analog computing or optical processing. The flexibility inherent in pixel by pixel manipulation possible through digital techniques has to be weighed against theoretically faster approaches involving electronic analog computing (with an associated inflexibility in implementing logical statements) and against the fundamentally parallel nature of optical processing (i.e., spatial frequency filtering via lens transformation and optical filters for image enhancement) with its associated "instantaneous" throughput and considerable inflexibility The above alternatives are currently represented by the following options:

1) General Purpose Digital Processors - typically large computers such as an IBM 360/75, Univac 1108, or CDC 6500 in which the logical statements and subroutines are programmed through conventional software.

2) Specialized Hard Digital Components - digital logic implemented by a network of solid state electronic components organized typically with a high degree of modularity, frequently to the logical operation level (i e , add, and/or, etc.) This approach offers primarily the advantages of higher processing efficiency in sequential operations by eliminating or minimizing executive control overhead and communication with a central processing unit, and the possibility of many identical parallel circuits to achieve high throughput The obvious disadvantage is the difficulty of reprogramming the "hardwired" black boxes or the cost and time of adding new boxes.

3) Electronic Analog Computers - most frequently implemented as a hybrid system where a relatively small digital computer is used to compute and control the setting of switches and potentiometers to initialize or set-up the analog circuitry.

4) Electro/Optical Processing - this may be considered as essentially a recording or display technique in which some effective "processing" is performed by variably biasing the electronic functions Typically, an input image is scanned by a vidicon tube with a small beam spot size (representing the resolution element desired), corrections or biases are computed either digitally or with analog circuitry, and a new image is written or displayed by imposing the corrections on deflection commands.

5) Photo/Optical Processing - the complete range of manipulations, corrections and enhancements possible through conventional photographic film processing.

6) Optical Processing - primarily based on the transformation properties of lenses and spatial frequency filtering by physically placing optical masks in the transform plane to eliminate structured noise (e g., a herringbone pattern in a raw image introduced by cyclic interference with the sensor from other on-board components) or to sacrifice certain selected spatial structure information to enhance other information of interest.

The one obvious additional option to the above list is the practical combination of any of the six approaches in a way that could hopefully maximize the utility gained from the attractive features, and minimize the penalties arising from the weak features, of each This then, is the fundamental task of beginning conceptual design and synthesizing the ground processing system.

5.0 SYSTEM SYNTHESIS APPROACH

The approach to synthesis and design of a system concept is presented in this section. The intent is to organize the major system functions comprehensively and to generalize the system structure where possible. By this approach it is hoped to provide an organized way of thinking about the processing system structure, and its necessary functions and equipments. This, in turn, may facilitate inclusion of new and advanced processing techniques as they develop, as well as accommodation of current methods. In a sense, the approach presented can be considered as an aid to the system designer. In view of the fact that there exists many alternatives with many design decisions to be made, the intent has been to minimize the difficulty of these decisions by clearly identifying the practical options.

The overall design process can be viewed as having four major phases: the designer exercises the general approach described within this section; the designer selects a specific functional flow and associated equipment (described step-by-step in Section 5.5), the designer evaluates the performance of his "point design" using the System Performance Simulation (Section 6.0); the designer repeats the previous phases through an iterative process until a system design is found which satisfies his performance requirements.

5.1 Input Data Workload

An obvious and fundamental requisite exists when approaching the design of a ground processing system. the designer must know what the system is to produce. He must either have, or postulate, an explicit description of the output data products and their characteristics. Obtaining this quantitative information implies defining the attributes of data products through an extensive dialogue with the would-be user agencies, as discussed in Section 3.0 "Required Data Products."

Given that definition of the data products is achievable for a given design case; two basic alternatives exist for providing an input raw data workload (nature, volume, and frequency of the source sensor data) to the system.

Option 1 - assume that the data acquisition capability of an existing or planned platform drives the ground system. An example would be to assume that the ERTS A RBV and MSS supplied the input imagery and to eventually ask the question through design evaluation, can the required output data products be satisfactorily generated with this assumed input?

Option 2 - work backwards from a knowledge of the required products (and their attributes as defined in Section 3.2) to an estimate of what the input data should be (an estimation method is described in Section 5.5). This estimate would then be refined through the design and evaluation iterative process.

The implication of exercising this second option would appear to be an emphasis on asking the logical question, how much data do I need?; as opposed to asking, how do I process and utilize all of the data the existing sensors are capable of generating? Additionally, this approach permits the use of the performance simulation to effectively specify the characteristics of future sensor systems and platforms. This latter utility would appear to be both timely and appropriate in view of the rapid advances in sensor technology and output capacity, relative to the technology for processing the data.

5.2 System Functional Organization

Figure 5-1 illustrates the top level functional organization of an image processing system. This figure shows the interrelation of six major functional categories:

- preparation and conversion
- correction
- correlation
- manipulation
- classification and recognition
- output products

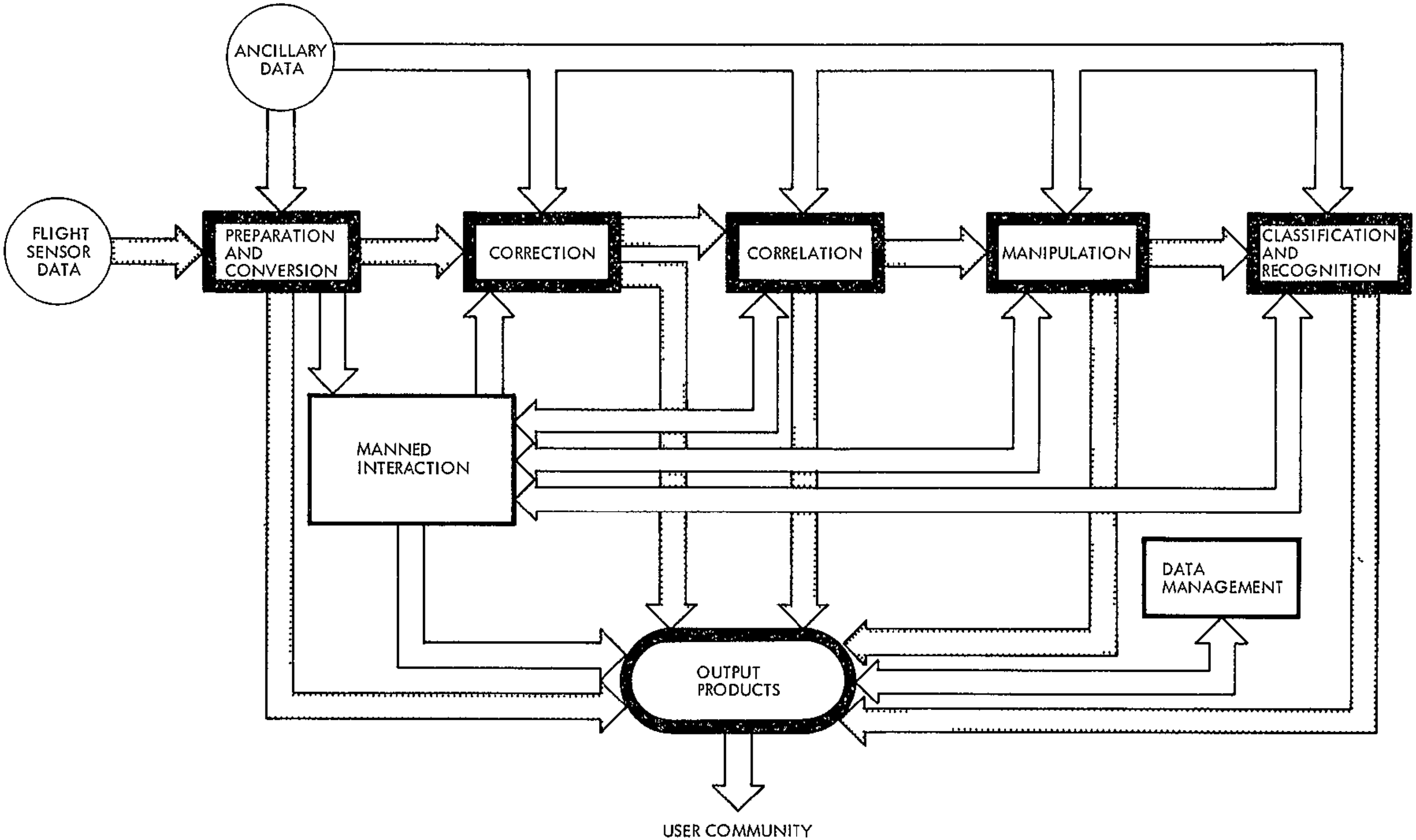

Figure 5-1. Functional Organization of an Image Processing System

These categories are considered to be the primary functional areas through which data would flow in a high throughput, operationally oriented system. To a first approximation the flow may be considered to move left to right, from preparation and conversion to classification and recognition, with a progressively increasing sophistication and difficulty of processing. Exit from this progression should be considered to be possible at any intermediate point, resulting in a viable output product

The above six major functional categories are supported by the functions of "manned interaction" and "data management." The importance of these two functions is minimized only in that they are not envisioned as contributing to the high throughput aspect of production of data products.

Figure 5-1 does not attempt to depict the many alternative paths possible, or the feedback iterative loops. It only attempts to provide a structure and simplified flow for the major categories of processing functions. These categories are, however, believed to comprehensively accommodate any meaningful form of image processing. The following section attempts to identify most of these meaningful operations within the major categories and describes them as "modular processing functions."

5.3 Modular Processing Functions

A set of functions within the above categories has been defined according to the following criteria:

First - the functions should be modular and somewhat equivalent in scope (i e., the functions should be defined at a discrete processing step level and this level should represent the smallest divisible entity in terms of image processing, where possible)

Second - the functions should be initially defined independently of the equipments or devices by which they might be implemented or performed

Third - an attempt should be made to include all probable processing functions irrespective of their current feasibility

Table 5-1 enumerates and defines this initial set of modular processing functions by major category. Figures 5-2 through 5-9 show the probable alternative flow paths through these modular functions by major category. Again, these functional flow charts serve as an aid or checklist to the designer (an aid which is derived essentially independent of hardware considerations) whereby he may specify the functional capability of the system at a level of detail permitting a subsequent selection of equipment.

A discussion of the functional categories follows:

Preparation and Conversion - This group of processing functions provides for accepting imagery data in various media and formats. The input is assumed to arrive from three basic sources:

- flight tapes and film from the onboard sensors representing the primary imagery of interest
- flight tapes representing ancillary data (attitude, ephemeris, voice annotation, etc) from the onboard platform
- supporting ancillary data which is historic or statistical in nature, or data that comes form other sensor sources which complements the primary data (e.g , ground truth data collected by in situ instrumentation or low altitude aircraft underflights)

Once this input data is reformatted, the next significant function is that of merging the imagery with ephemeris information (or other positional information, e.g., geodetic ground control points) to produce a complete data set. Following this processing, a minimum of six conversion options are open to obtain any desired image domain from any other (i.e., digital, video or film). This basic set of modular functions for conversion may be exercised within any of the major functional categories, at many intermediate processing steps.

Table 5-1 Modular Processing Functions

I PREPARATION AND CONVERSION

DEMØDE - Demodulating/Decompacting/Demultiplexing

REFØRM - Reformatting

EPHEM - Geocentric coordinate assignment based on attitude and ephemeris calculations

CØNVER - Image domain conversion

A-TØ-D - Convert video to byte sequence

D-TØ-A - Convert byte sequence to video

SCANIM - Convert transparency to video

RESCAN - Convert video to hard copy

II. CORRECTION

GRNCØN - Location and measurement of ground control points

GEØCØR - Geometric location and frame correction based on ground control points

RESEAU - Abstracting calibration fiducials

CURVAT - Geometric correction in image projection due to earth curvature

TERAIN - Geometric correction in image projection due to height profile of scene terrain

ATMØS - Geometric correction due to refraction in atmosphere

PØSITN - Geometric displacement correction due to errors in platform position

ATITUD - Geometric correction due to error in sensor pointing

RATE - Geometric correction for smear and distortion due to drift rates of platform

SENGEØ - Geometric correction due to sensor electronics

ØPTGEØ - Geometric correction due to sensor optics

TIMGEØ - Geometric correction due to recording system timing signal error

ABSØRP - Radiometric correction due to atmospheric absorption and background luminance

II. CORRECTION (Cont'd.)

RADTØM - Radiometric correction due to signal noise

SENRAD - Radiometric correction due to sensor detector/film response

ØPTRAD - Radiometric correction due to sensor optics aberrations

RADCØN - Location and calibration of radiometric reference target on the ground

RADCØR - Radiometric correction based on reference target calibration

III. CORRELATION

SELECT - Select image data sets for registration

SCALIM - Change scale of image through reduction or enlargement

MATCH - Select and measure match points

REGTRN - Produce registration through translation of image data set

REGRØT - Produce registration through rotation of image data set

MERGE - Correlate and annotate ancillary data to image data sets

IV. MANIPULATION

ZØØMIN - Select geographical area of interest within an image data set

MØSAIC - Produce image mosaic by combination of data sets

RESØL - Change effective spatial resolution by averaging between pixel rows and columns to reduce resolution

GRID - Insertion of a reference grid into image data set

SMØØTH - Interpolation between neighboring pixels to minimize noise

CØNTRA - Alter contrast by changing intensity values by a constant value or by mapping into another gray scale range

THRESH - Produce an image data set by zeroing out all intensity levels below or above a specified threshold

IV. MANIPULATION (Cont'd.)

NEGIM - Reverse intensity value range of data set

SUBADD - Subtract or add two registered data sets

TRANSF - Modify the intensity values in an image data set by an input functional transformation

PATCH - Replacement of a missing image scan line by interpolation between adjoining lines

TRANSL - Translation of an image data set with respect to a reference grid

RØTATE - Rotation of an image data set through a specified angle

INTERP - Location of picture points off integer scan rows and columns through two dimensional linear interpolation

SPAFRQ - Generation of forward and inverse transformations (i.e., Fourier and Hadamard) of an image data set

FILTER - Multiply a given filter matrix by a transformed data set

V. CLASSIFICATION AND RECOGNITION

TRNSFM - Rotates observational data vectors using a principle axis transformation

CLUSTR - Forms groups consisting of pixels with observations which are close to each other in observation space

FACTØR - Computes the mean vector, covariance matrix, eigenvalues, eigenvectors and the angle between each eigenvector and the mean vector of a cluster of data

DTRMIN - Determines location of areas of known composition

TRAINS - Computes signature of training samples (subset of FACTOR)

MAXLIK - Classifies input observational vector using a maximum likelihood formulation

MIXTUR - Decomposes data vectors along known basis vectors

USEIG - Retrieves a priori signature

V. CLASSIFICATION AND RECOGNITION (Cont'd)

QUANTZ - Classifies pixels based upon the magnitude of a given component of the observation vector

ASØCAT - Performs any necessary associations of clusters prior to output

VI. MANNED INTERACTION

DISPLA - Presentation of imagery or control data to a console situated operator

ØPTPRJ - Optical projection of image film transparencies

CØMGEN - Computer driven display on monochromatic or color CRT

MØNITR - The process of manned monitoring of a processing subsystem or image set data at intermediate processing points via a computer driven display or optical projection system

SCREEN - Screening of image set data by selecting a reduced volume for subsequent processing

CØNTRL - Manned intervention in the processing flow by designation of subsequent processing steps

ANALYZ - Analysis and interpretation of data displays by man situated at computer driven displays or optical projection systems

VII. OUTPUT PRODUCTS

FØTMAP - Assembles necessary gridding and annotation information for preparation of photomap

PRINTS - Produce photographic prints

CØLCØM - Produce color composites

SPCSLI - Performs spectral slicing

TRANSP - Prodcues transparencies

THEMEX - Produces thematic map

CØNTUR - General purpose contouring

ØVRLAY - Produces photograph and map overlays

STAPLT - Produces plots of statistical parameters

HISGRM - Develops histograms

VII. OUTPUT PRODUCTS (Cont'd.)

SCTDIG - Produces scatter diagrams

SPCMES - Determine transmissivity of transparencies

XYLØC - Automatically determines x-y location of points of interest

HDDDTP - Produces high density tape

CCTPRØ - Produces computer compatible tape

SMLCØM - Produces special purpose data analysis program from available algorithms

INVENT - Produces listings of automated inventories resulting from classification of imagery

STSUM - Produces listings of statistical summaries

PRDSUM - Produces summaries of production activities of ground data handling system

VIII. DATA MANAGEMENT MODULAR FUNCTIONS

ANØTAT - Annotation of ancillary complementing information to an image data set

INDEX - Assignment of search code to image or ancillary data sets

CATLØG - Entry of description of data sets and index code to master catalog

STØRE - Physical storage of source data sets in data management system

SEARCH - Search or index code for data sets to be retrieved

RETRIV - Physical retrieval or display of data sets of interest

TRNACT - Bookkeeping of records of activity in storage/retrieval system

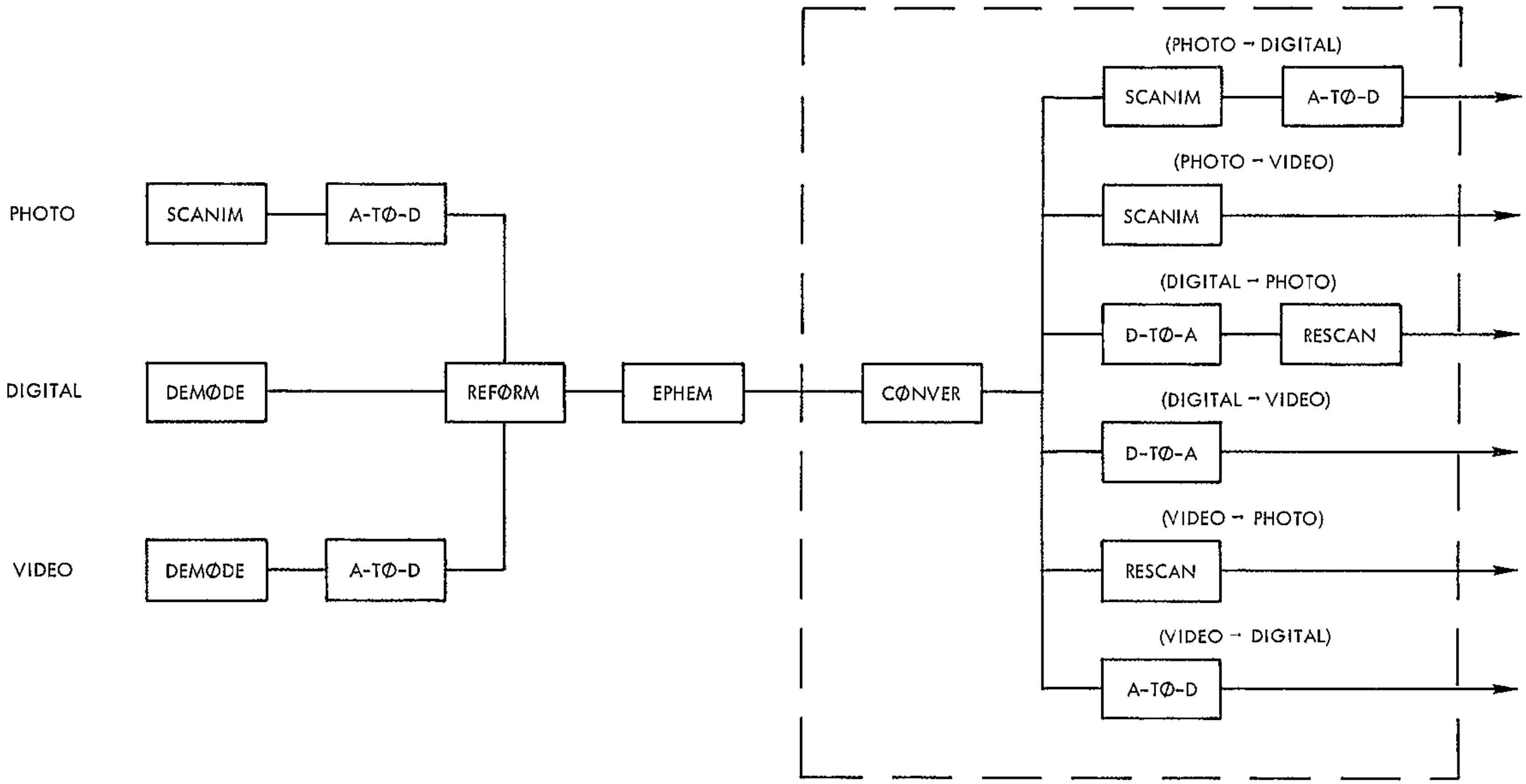

Figure 5-2. Preparation and Conversion Functional Flow

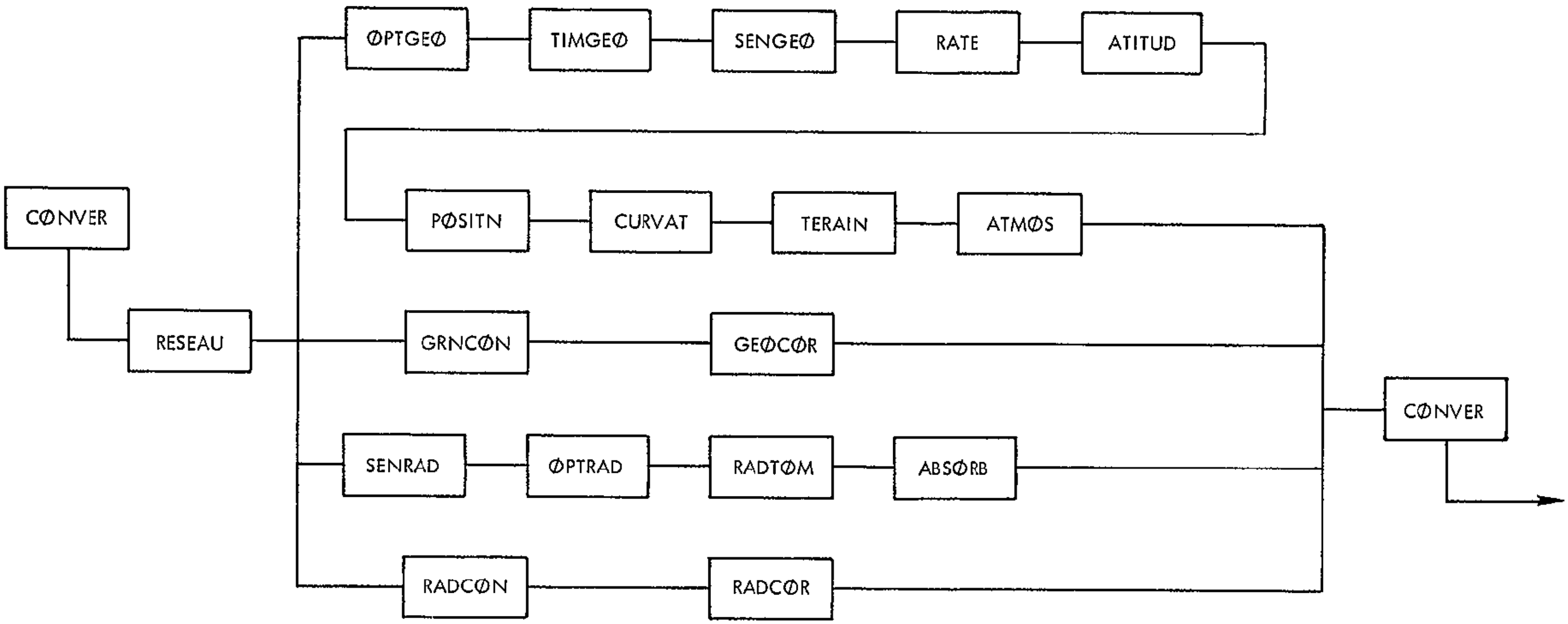

Figure 5-3. Correction Functional Flow

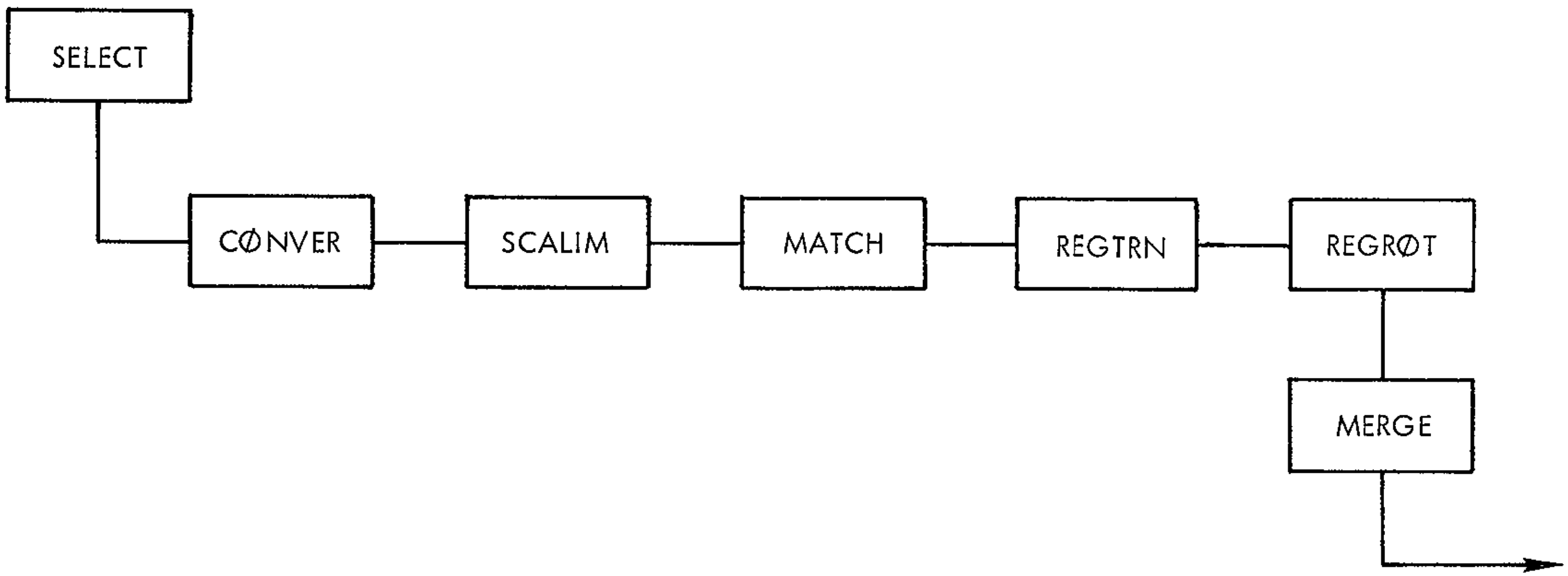

Figure 5-4. Correlation Functional Flow

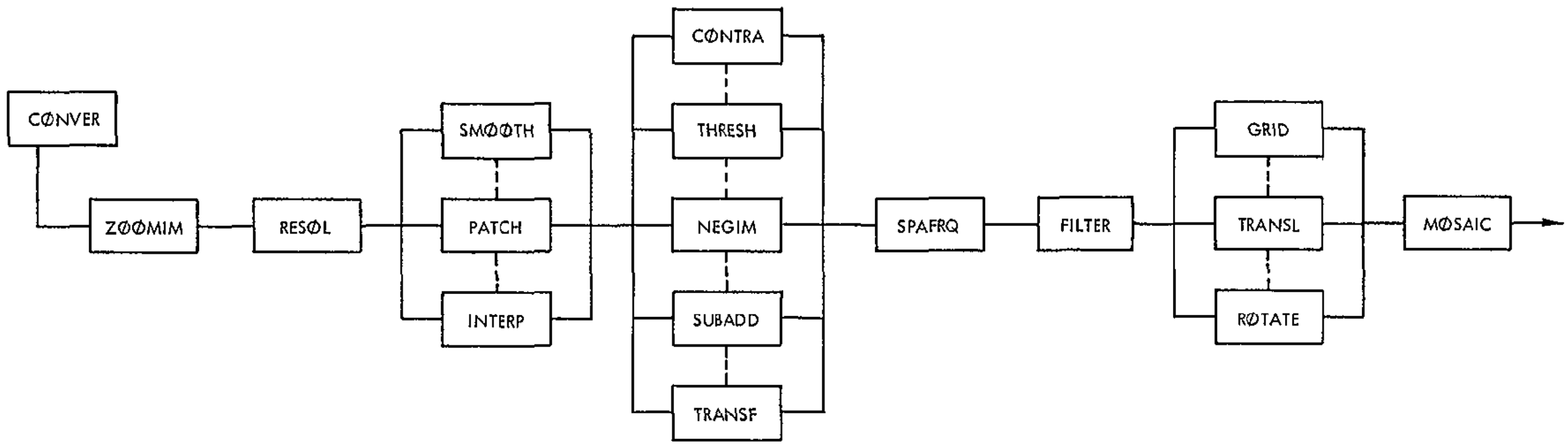

Figure 5-5. Manipulation Functional Flow

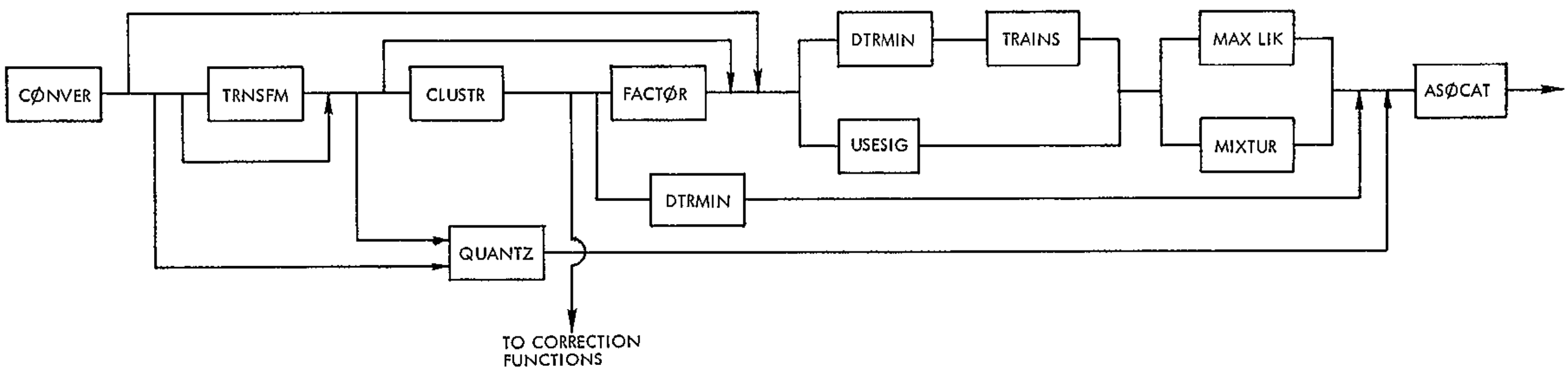

Figure 5-6. Classification and Recognition Functional Flow

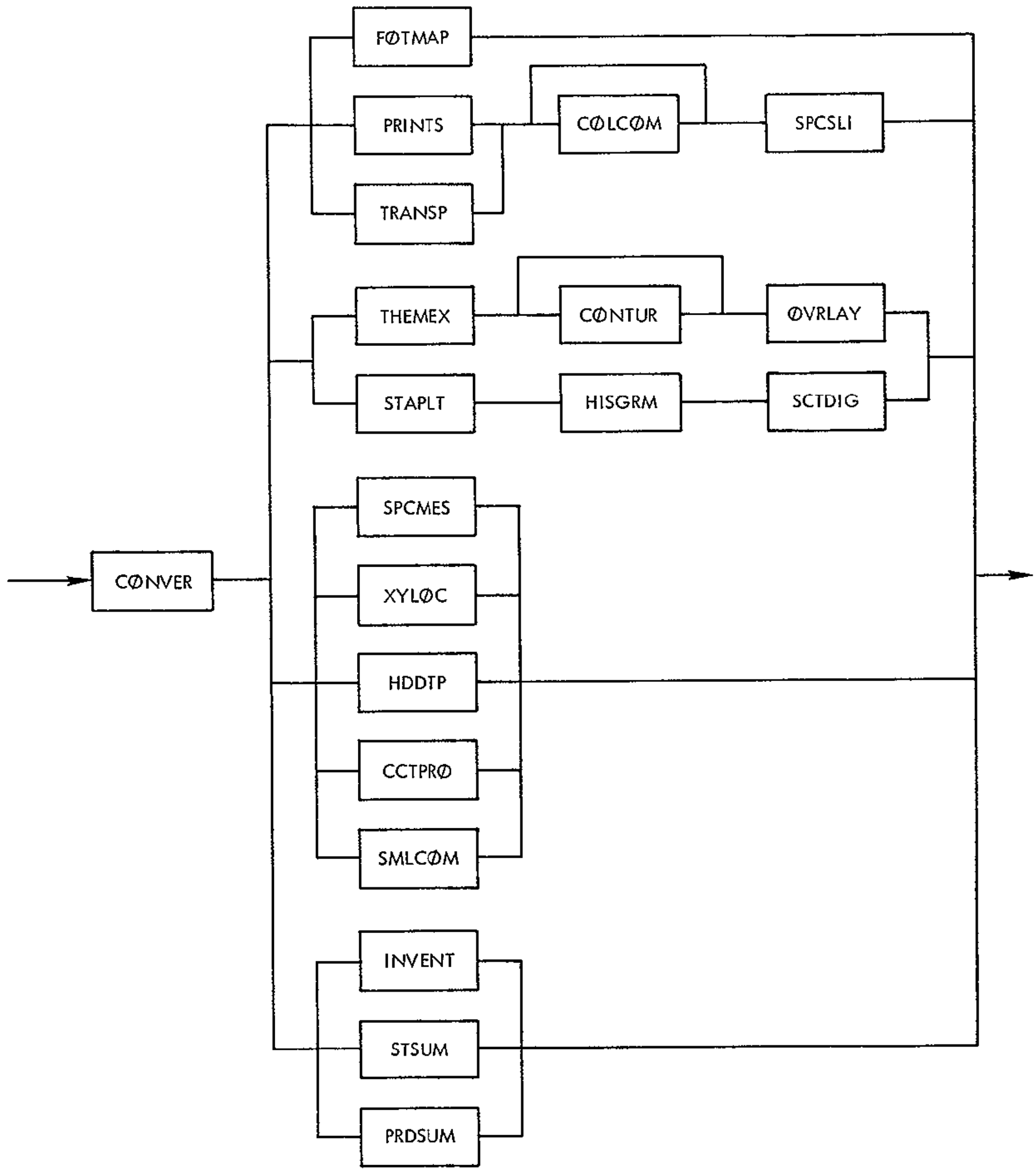

Figure 5-7. Output Products Functional Flow

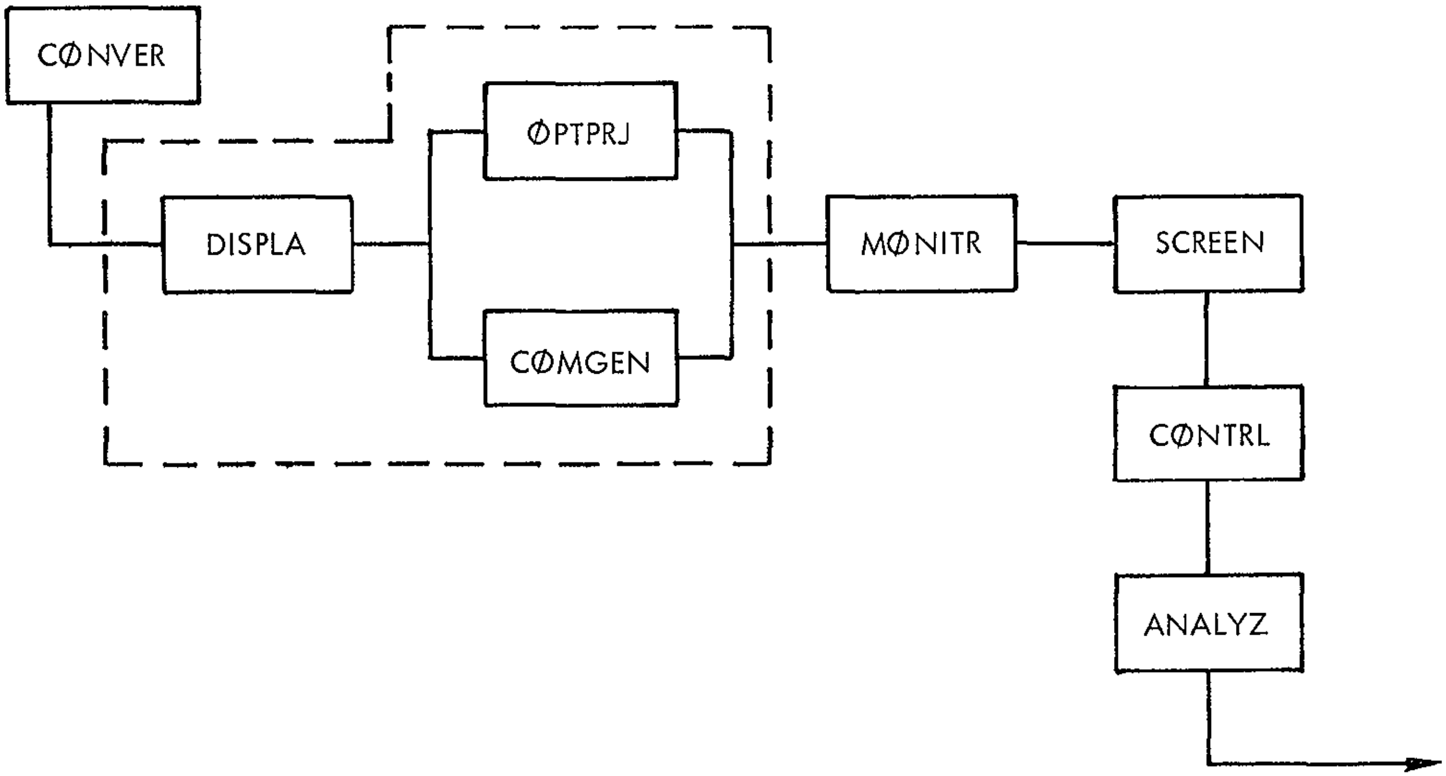

Figure 5-8. Manned Interaction Functional Flow

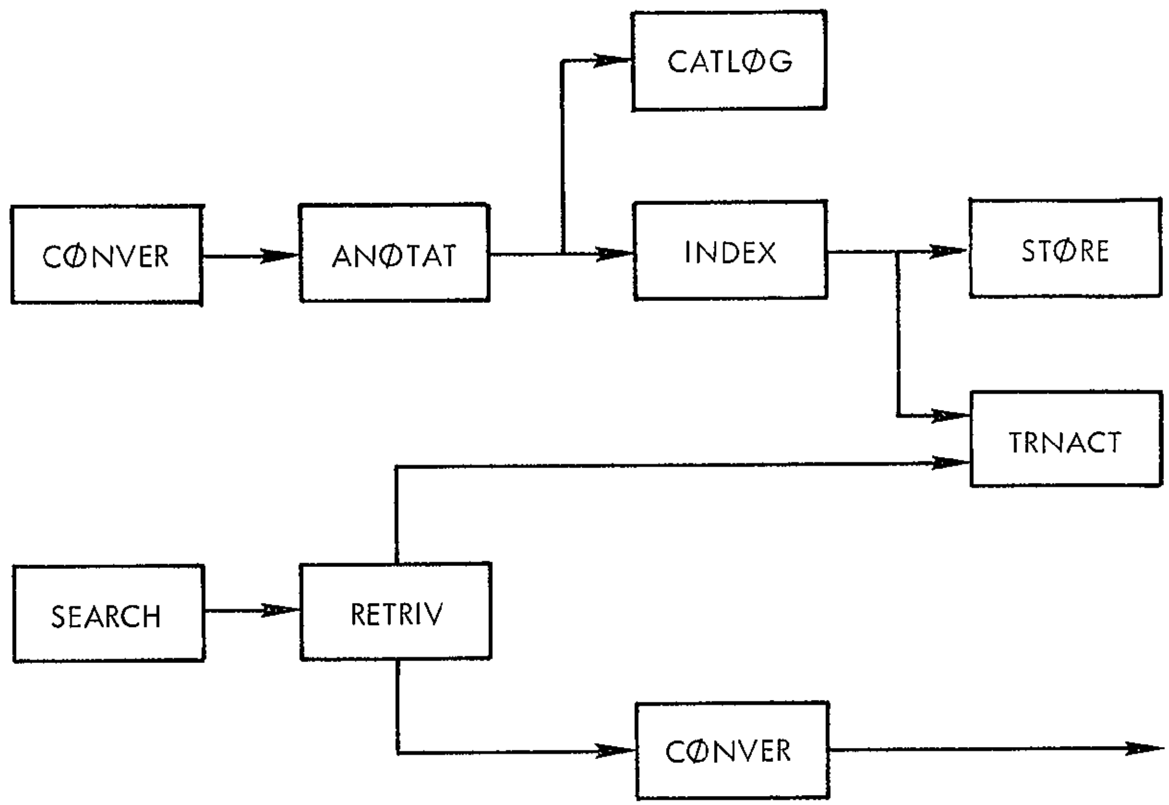

Figure 5-9. Data Management Functional Flow

Correction - The set of functions under this category are intended to perform either geometric or radiometric correction to the imagery. Two basic alternative paths are shown for each type of correction representation and modeling of the various error sources and applying incremental corrections based on these models, and a form of absolute empirical correction based on either surveyed and visible landmarks used as ground control points for geometric correction, or calibrated light sources on the ground (e.g., laser "searchlights") for radiometric correction.

Correlation - This category addresses the problem of registration of an image data set to a reference set. Typically, two images of the same ground scene but in different spectral bands would be brought into conjunction or registration. Additionally, this category includes the merging of ancillary data with the primary imagery (e.g., superimposition of statistical data on primary imagery).

Manipulation - Functions performed in this category typically add no new information content to the image but instead· restore missing elements, manipulate intensity levels, enhance by filtering spatial frequency information or perform operations which assist in interpretation (e.g , superimpose a grid or construct large photomaps by mosaicing or piecing together adjoining frames)

Classification and Recognition - Included here are the various algorithms and decision rationale for pixel by pixel classification of multispectral imagery data. Classification is based only on the spectral information content of the data and may proceed, in general, by: forming groups of pixels with observations which are "close" to each other in the observation space (i.e., clustering); or by classifying input observational vectors using a maximum likelihood formulation. Provision is also made for selecting training samples, computing the sample reference signatures and using this to associate given clusters with the known objects in the ground scene.

Output Products - This category includes all functions necessary to produce the family of viable outputs at various intermediate stages of processing. The functions deal in general with the printing, plotting, film recording and photo processing of imagery data sets and relevent ancillary data.

Manned Interaction - Included here are the manned or man-assisted functions of monitoring, screening, controlling and interpretation. These functions are assumed to be applied to either the primary imagery data (or ancillary data) or to the allocation and control of the processing subsystem resources Both on-line, interactive functions (e.g., CRT display driven by a computer) and off-line functions (e.g., man situated at a rear projection optical viewer) are included.

Data Management - This category includes storage and retrieval of imagery data and derived statistics on subsystem performance. Functions within this category are intended primarily to accommodate relatively short term retention of data for the purpose of correcting and calibrating subsequent processing of primary imagery.

5.4 Equipment/Device Selection

The definition of required modular processing functions was performed independently of devices or equipment types necessary to implement the functions. The end result of the synthesis effort, however, must be the selection and sizing of equipment to accommodate the processing functions The system designer must be capable of producing a tentative subsystem/ hardware schematic prior to assessment of overall system performance.

To aid in the equipment selection process, and to help identify equipment alternatives, a general hardware concept is required. This concept is illustrated in Figure 5-10 "Master Equipment/Device Schematic." This concept is based on a high degree of centralized digital processing capability surrounded by various "work stations." The work stations shown in Figure 5-10 are:

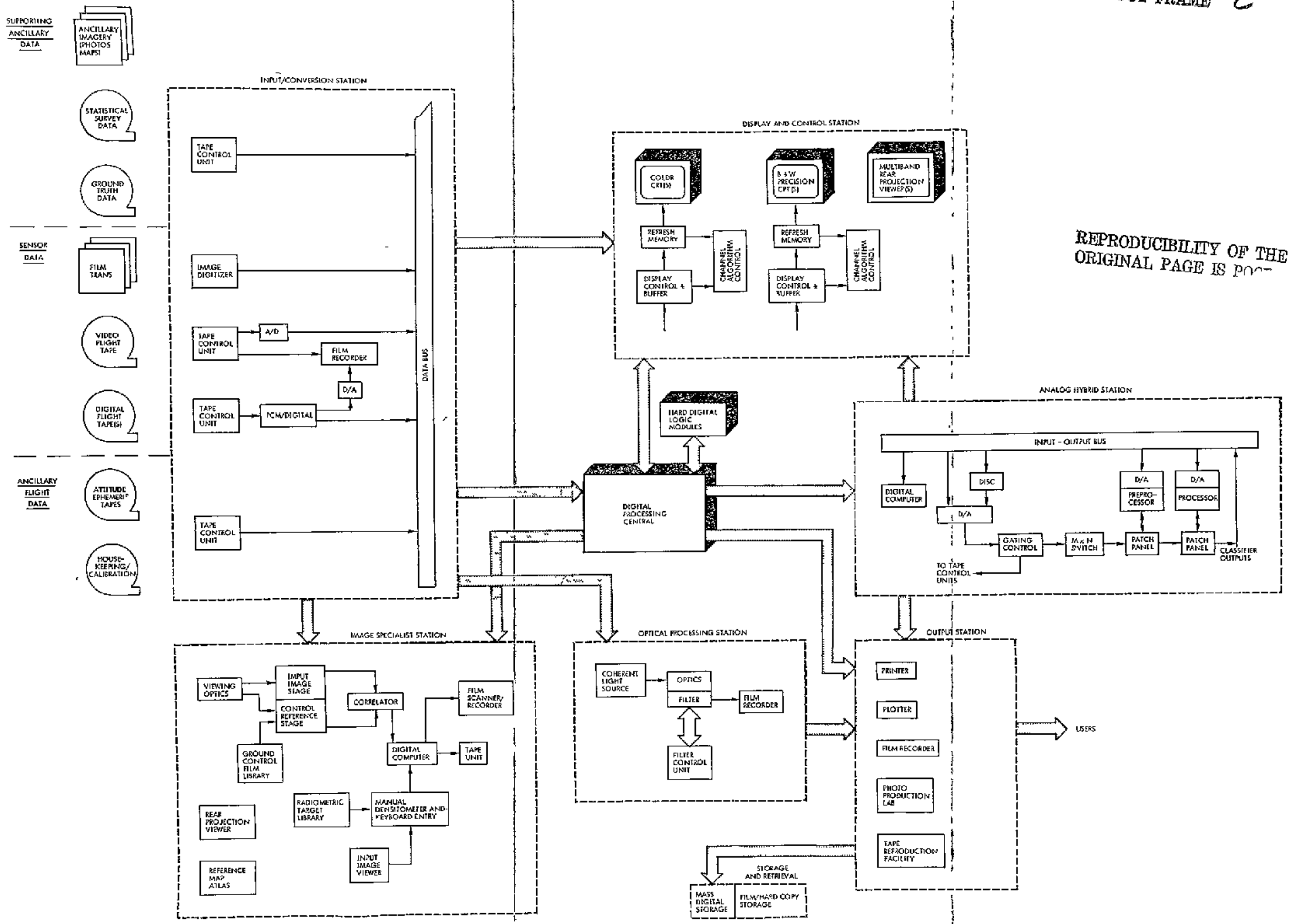

Figure 5-10. Master Equipment/
Device Schematic

Input/Conversion Station	Characterized by reformatting, conversion and recording equipment
Display and Control Station	Comprised typically of CRT display and optical projection equipment
Image Specialist Station	Equipment employed here is typically for image mensuration, viewing and auto or manual correlation
Optical Processing Station	Optical devices/lenses, light sources, filter fabrication and control, and film readers
Electronic Analog Station	Typically a large scale, general purpose hybrid computer
Output Station	Film and tape recorders, scanners, photo processing lab, line printers and plotters
Storage/Retrieval Station	Mass storage for digital data (e.g., drums, disks, tapes, etc) and storage units for film reels and other hard copy

The centralized digital processing resource is considered to take any of several forms including: a single large scale general purpose processor, parallel or multiprocessing systems, or multiple midi or mini computers. Supporting any of these architectures, the alternative of solid state special purpose modular processors is considered in two roles.

- special purpose modules perform "front end" preprocessing
- special purpose modules perform the bulk of all processing in multiple, parallel units under the control of a conventional software programmed computer

The inherent work station organization in the "Master Schematic" is believed to be a viable and practical approach from both a facility layout consideration, as well as a concern for flexibility and growth potential.

5.5 Designer's Guide

The following is a step-by-step scenario of the process through which a designer may start with user's data products requirements and proceed to synthesis of a trial processing system design.

Step 1 - Designer must have an explicit description of the data products to be produced by the system These products will most probably be a reduced set of the product family illustrated in Figure 3-3. The specific attributes or characteristics of these products are described in Section 3.2.

Step 2 - Designer defines a raw input data volume based on the acquisition capability of an existing or planned platform. This workload will define the volume, frequency and quality (i.e., spatial and spectral resolution) of the input imagery.

Step 2 (Optional) - Designer estimates a raw input data volume required based on analysis of the required data products. An aid in providing this estimate is shown in Table 5-2.

Step 3 - Designer selects the desired major categories, and modular functions within the categories, to be performed. Figure 5-11 "Data Products vs. Functional Categories" provides an aid in performing this selection.

Step 4 - Designer determines the tentative flow of the selected modular functions based on the alternatives shown in Figures 5-2 through 5-9.

Step 5 - Using the "Equipment/Modular Function Matrix," Figure 5-12, and the "Master Equipment/Device Schematic," Figure 5-10, the designer specifies equipment types and interconnection.

Step 6 - Designer estimates the size of individual devices and the tentative number of parallel units based on the overall input data volume (this estimate is simply a starting point for the subsequent design iteration based on performance simulation).

Step 7 - For those functions to be implemented by digital logic, the designer specifies software or solid state specialized component execution.

Step 8 - Designer specifies a software top level program organization (as described in Section 6.4 "Computer System Simulation Program") and the central digital processing architecture.

Step 9 - For the equipment types selected, the designer must specify the required performance and sizing parameters as required by the respective models (example shown in Section 6 5)

The above steps, as illustrated in Figure 5-13, result in a degree of system definition that permits the simulation of throughput performance, as described in the following section.

Table 5-2 Input Data Volume Estimator

DATA PARAMETERS

RESOLUTION REQUIREMENTS	FT (P1)
ENCODING LEVEL	(P2)
INTERVAL BETWEEN OBSERVATIONS	DAYS (P3)
NUMBER OF SPECTRAL BANDS	(P4)
DESIRED SWATH WIDTH	N MI (P5)
AREAL EXTENT	N MI^2 (P6)

SIMULATION PARAMETERS

$$\text{FRAMES OF IMAGERY/ONE TIME TOTAL COVERAGE} = \frac{P6\ (\times\ P4 \text{ FOR MULTIBAND IMAGERY})}{P5^2}$$

$$\text{BITS/TOTAL ONE TIME COVERAGE} = \frac{(6080)^2\ P6 \times P4 \times P2}{P1^2}$$

$$\text{AVERAGE FRAMES/DAY} = \frac{P6\ (\times\ P4 \text{ FOR MULTIBAND IMAGERY})}{P5^2 \times P3}$$

$$\text{AVERAGE BITS/DAY} = \frac{(6080)^2\ P6 \times P4 \times P2}{P1^2 \times P3}$$

	PREPARATION AND CONVERSION	CORRECTION	CORRELATION	MANIPULATION	CLASSIFICATION AND RECOGNITION
PRINTS AND TRANSPARENCIES	EMPHASIS ON IDENTIFICATION OF PROMINENT FEATURES IN HIGH QUALITY RAW IMAGERY	APPLICATION REQUIRES PRECISE KNOWLEDGE OF ABSOLUTE AND RELATIVE LOCATION OF OBJECTS SIGNIFICANT SPECTRAL ERRORS IN IMAGERY	SCALE ORIENTATION OR IMAGE BOUNDS SPECIFIED OVERLAY	VISUAL CHANGE DISCRIMINATION HIGHLIGHTING FEATURES	FALSE COLOR HARD COPY REQUIRED
PHOTOMAPS	—	—	ONLY IDENTIFICATION OF LANDMARKS IN IMAGERY REQUIRED	GRID REQUIRED	THEME EXTRACTION
THEMATIC MAPS	ONLY GROSS VISUAL ASSOCIATION (e g METEOROLOGICAL INFORMATION PLOTTED ON IMAGE) REQUIRED	PLOTTING BASE IS IMAGE	IMAGERY INFORMATION IS TO BE SUMMARIZED ON MAP	FUNCTIONAL TRANSFORMATIONS OF IMAGERY ARE TO BE DISPLAYED	CLASSIFICATIONS TO BE DISPLAYED ON MAP
STATISTICAL PLOTS	GROSS PROPERTIES OF RAW DATA MUST BE KNOWN BEFORE PROCESSING SEQUENCE CAN BE SPECIFIED, QUICK LOOK	EFFECTIVENESS OF CORRECTION PROCESSES MUST BE ASSESSED BEFORE PROCEDING	PLOTS ARE TO BE USED TO DETERMINE THAT DATA SELECTED FROM IMAGE MEET EXPECTED STATISTICAL PROPERTIES	—	—
SPECTRAL MEASUREMENTS	HIGH CONFIDENCE IN GEOMETRIC AND SPECTRAL FIDELITY	SPECTRAL MEASUREMENTS OF TOTAL IMAGE OR LOOSELY DEFINED REGIONS	STRICT REQUIREMENT FOR PRECISENESS IN SAMPLE SELECTION	THRESHOLDS SET FOR EXTRACTION OF PARTICULAR MEASUREMENT	—
X-Y LOCATION	—	OBJECTS IN IMAGERY READILY VISIBLE MANUAL MEASUREMENT OF COORDINATES	LOCATION OF OBJECTS IN IMAGERY FASCILITATED BY MACHINE PROCESSING AUTOMATIC MEASUREMENT OF COORDINATES	X-Y LOCATIONS DESIRED IN REFERENCE COORDINATES	OBJECTS IN IMAGE MUST BE CLASSIFIED BASED UPON SPECTRAL PROPERTIES BEFORE MENSURATION
HIGH DENSITY TAPE	ARCHIVAL OR DELIVERY REQUIREMENTS CREATE DESIRE TO LIMIT NUMBER OF TAPES				
COMPUTER COMPATIBLE TYPE	USER HAS DIGITAL CAPABILITY TO PROCEED FROM THIS POINT				
INVENTORY SUMMARY	—	—	SUMMARY OF KNOWN FEATURES IN IMAGERY	IDENTIFICATION OF PORTION OF IMAGERY SATISFYING THRESHOLD LEVEL	CATEGORIZATION OF ELEMENTS OF IMAGERY
STATISTICAL SUMMARY	ANALYSIS OF BIAS AND NOISE CHARACTERISTICS REQUIRED TO DETERMINE PROCESSING REQUIREMENTS	EFFECTIVENESS OF CORRECTION PROCESSES MUST BE ASSESSED BEFORE PROCEDING	BEHAVIOR OF SIGNATURES OF TRAINING SITE TO BE ANALYZED AGAINST STANDARDS	DETAILED ANALYSIS OF EFFECTS OF FILTERING REQUIRED	DETAILED ANALYSIS OF CLASSIFICATION DECISIONS REQUIRED

Figure 5-11. Data Products vs. Functional Categories

	REFORMAT EQUIP	A TO D CONVERTERS	D TO A CONVERTERS	DENSITOMETER	IMAGE DIGITIZER	COLOR CRT	B&W PRECISION CRT	REAR PROJ VIEWER	DIGITAL COMPUTER	HYBRID COMPUTER	OPTICAL COMPUTER	HARD DIGITAL LOGIC	E B R	CRT SCANNER/WRITER	IMAGE CORRELATOR	FILM RECORDER	PLOTTERS	PRINTERS	COMP COMPAT TAPE	HDDT RECORDER
PREPARATION AND CONVERSION																				
DEMØDE																				
REFØRM	X																			
EPHEM									X				X			AX				
CØNVER	X	X	X	X	X															
A-TØ-D		X																		
D-TØ-A			X																	
SCANIM				X	X															
RESCAN													X	X	X	X				
CORRECTION																				
GRNCØN									X			X			X					
GEØCØR									X			X	AX	AX						
RESEAU									X				AX	AX	X					
CURVAT									X		X		AX	AX						
TERAIN									X				AX	AX						
ATMØS									X				AX	AX						
PØSITN									X	X	X		AX	AX						
ATITUD									X				AX	AX						
RATE									X				AX	AX						
SENGEØ									X		X	X	AX	AX						
ØPTGEØ									X		X	X	AX	AX						
TIMGEØ									X				AX	AX						
ABSØRB									X				AX	AX						
RADTØM									X		X		AX	AX						
SENRAD									X		X		AX	AX						
ØPTRAD									X		X		AX	AX						
RADCØN									X						X					
RADCØR									X				AX	AX						

AX denotes auxiliary function

Figure 5-12. Equipment/Modular Function Matrix

	REFORMAT EQUIP	A TO D CONVERTERS	D TO A CONVERTERS	DENSITOMETER	IMAGE DIGITIZER	COLOR CRT	B&W PRECISION CRT	REAR PROJ VIEWER	DIGITAL COMPUTER	HYBRID COMPUTER	OPTICAL COMPUTER	HARD DIGITAL LOGIC	E B R	CRT SCANNER/WRITER	IMAGE CORRELATOR	FILM RECORDER	PLOTTERS	PRINTERS	COMP COMPAT TAPE	HDDT RECORDER
CORRELATION																				
SELECT									X	X										
SCALIM									X	X	X	X	AX	AX		AX				
MATCH									X					AX	X					
REGTRN									X	X	X		X	X						
REGRØT									X		X		X	X						
MERGE									X	X			X	X		X				
MANIPULATION																				
ZØØMIN									X	X	X									
MØSAIC									X	X	X		AX	AX		AX				
RESØL									X	X	X		AX	AX		AX				
GRID									X	X	X		AX	AX		AX				
SMØØTH									X	X	X	X	AX	AX		AX				
CØNTRA									X	X	X	X	AX	AX		AX				
THRESH									X	X	X	X	AX	AX		AX				
NEGIM									X	X	X	X	AX	AX		AX				
SUBADD									X	X		X	AX	AX		AX				
TRANSF									X	X	X	X	AX	AX		AX				
PATCH									X				AX	AX		AX				
TRANSL									X	X	X	X	AX	AX		AX				
RØTATE									X	X	X	X	AX	AX		AX				
INTERP									X	X	X	X	AX	AX		AX				
SPAFRQ									X	X	X	X								
FILTER									X	X	X	X								

Equipment/Modular Function Matrix (cont'd.)

	REFORMAT EQUIP	A TO D CONVERTERS	D TO A CONVERTERS	DENSITOMETER	IMAGE DIGITIZER	COLOR CRT	B&W PRECISION CRT	REAR PROJ VIEWER	DIGITAL COMPUTER	HYBRID COMPUTER	OPTICAL COMPUTER	HARD DIGITAL LOGIC	E B R	CRT SCANNER/WRITER	IMAGE CORRELATOR	FILM RECORDER	PLOTTERS	PRINTERS	COMP COMPAT TAPE	HDDT RECORDER
CLASS AND RECOGNITION																				
TRNSFM									X	X		X								
CLUSTR									X	X		X								
FACTØR									X	X		X								
DTRMIN									X	X		X								
TRAINS									X	X		X								
MAXLIK									X	X		X								
MIXTUR									X	X		X								
USESIG									X	X		X								
QUANTZ									X	X		X								
ASØCAT									X	X		X								
MANNED INTERACTION																				
DISPLA						X	X													
ØPTPRJ								X												
CØMGEN						X	X													
MØNITR						X	X	X												
SCREEN						X	X	X												
CØNTRL						AX	AX	AX												
ANALYZ						AX	AX	AX												

Equipment Modular Function Matrix (cont'd.)

OUTPUT PRODUCTS	REFORMAT EQUIP	A TO D CONVERTERS	D TO A CONVERTERS	DENSITOMETER	IMAGE DIGITIZER	COLOR CRT	B&W PRECISION CRT	REAR PROJ VIEWER	DIGITAL COMPUTER	HYBRID COMPUTER	OPTICAL COMPUTER	HARD DIGITAL LOGIC	E B R	CRT SCANNER/WRITER	IMAGE CORRELATOR	FILM RECORDER	PLOTTERS	PRINTERS	COMP COMPAT TAPE	HDDT RECORDER
FØTMAP													X	X		X				
PRINTS													X	X		X				
CØLCØM																X				
SPCSLI				AX	AX											X	X	X		
TRANSP													X	X		X				
THEMEX				AX	AX				X	X		X				X	X			
CØNTUR																	X			
ØVRLAY																X	X			
STAPLT																	X	X		
HISGRM																	X	X		
SCTDIG																	X			
SPCMES				X	X											X	X	X		
XYLØC									X							X	X	X		
HDDDTP									X											X
CCTPRØ									X										X	
SMLCØM									X										AX	
INVENT									X									X		
STSUM									X									X		
PRDSUM									X									X		

Equipment Modular Function Matrix (cont'd.)

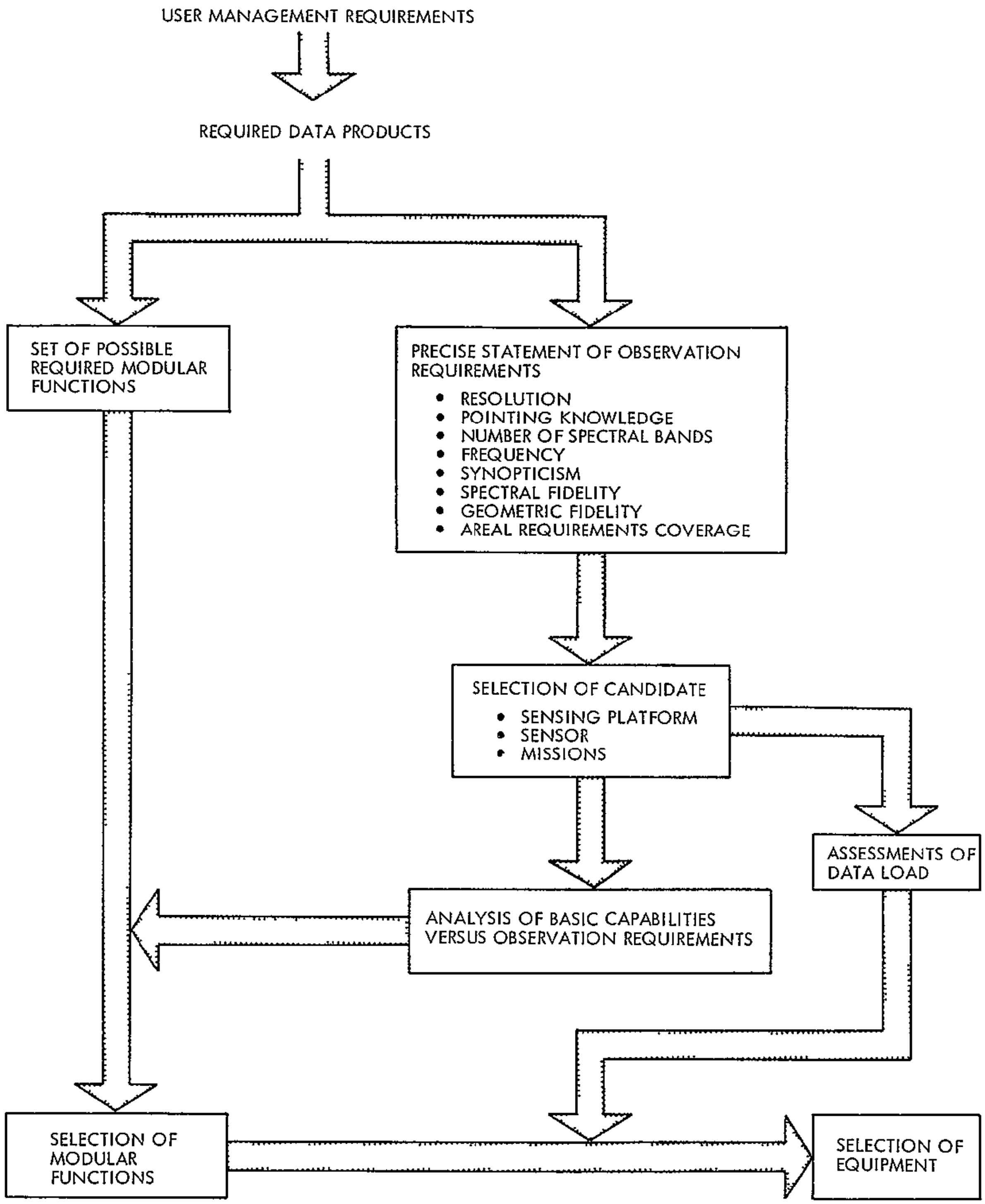

Figure 5-13. System Designer's Approach

6 0 SYSTEM PERFORMANCE SIMULATION

This section details a simulation concept developed to help design and/or evaluate a data processing facility It describes the need for an evaluation tool, what these tools (computer programs) are, how they simulate the system, how to prepare software and/or hardware models for them, and finally what outputs are received from the computer runs.

6.1 Simulation Objectives

As shown in Section 5.0 a total ground data processing facility for earth resources data would normally consist of a variety of equipment such as

- viewers
- image digitizers
- densitometers
- tape recorders/playbacks
- digital computers
- printers
- plotters
- film developers
- CRT's

and many other devices depending upon the type of data received and the processing to be performed. In addition to all of the equipment required, there would be steps in the reduction where analysts would greatly influence the flow of data. Some man interface functions include.

- operation of the equipment
- determining what data is to be processed
- view data from CRT's and introduce instructions into the computer for special operations
- transport data from one station to another

The effective flow of data and utilization of equipment therefore requires a data system which is described by many different variables such as·

- device speeds
- time required for a man to make a logical decision
- software routines to be used for data correction
- computer cycle time
- number of pieces of similar equipment

as well as numerous other detailed items which all introduce delays into the total system throughput.

Because of all of these variables and complexities, it is not intuitively obvious what ground station configuration will most efficiently process the data, maximize the use of equipment and minimize the cost of the total facility

In order to help the ground station designer answer these questions the "Equipment Simulation Program" (ESP) was developed. This program, along with its support program, "The Computer Simulation Program (CØMPSIM) helps the system designer determine what his system throughput will be. For each point design simulation he runs he can maintain subsystem cost records to relate to the equipment utilization results obtained by the program. After simulating a number of different system configurations he can then determine the most cost-effective system to perform his job.

6.2 Simulation Approach

The system simulation approach is based on the assumption that a data system should be thoroughly evaluated before purchase or lease of hardware The ideal situation would be to actually run the system on benchmark sets of data. However, since the total system is probably unique and the software is probably not yet developed, this approach is generally impossible. The next best approach is to model the components of the system and run computer simulations of the equipment processing given work loads. The results can then be analyzed and adjustments in the equipment types, number of configurations can be made

The simulation approach to detailed design of ground data facility is shown in Figure 6-1. Each circle represents a step in the selection procedure. First the data processing requirements are defined to the system designer. Typically the requirements consist of the amount of data to be processed and the end result products expected to be produced by the system Next, the designer must define the functional requirements This step consists of defining a flow of data through devices and computers and defining the processing required at each step. He must also define the computer programs required and what function each performs.

Now he must take the functional requirements and determine the equipment best suited for performing those functions. The designer may be some what constrained by a requirement to use some existing equipment, or he may be totally free to specify all equipment The data facility design must be such that the throughput requirements can be met, bottlenecks do not exist, and cost is minimized. Because of the trade-offs among these variables it becomes very difficult to synthesize one system configuration and be confident that that system is optimal. Therefore, it becomes desirable to evaluate the system on some basis other than hand calcualtions of its performance. Trying to follow the flow of data through many different devices and computer programs quickly becomes an overwhelming task. The need for a computer program to simulate the data flow and maintain key statistics becomes very obvious.

ESP and its support program CØMPSIM were designed for this task. ESP will simulate a flow of data through a set of various devices and maintain key statistics such as. percent utilization, maximum wait time for an entity of data, maximum length of the wait queue, etc. These are the statistics that locate bottlenecks and determine the utilization performance of the equipment.

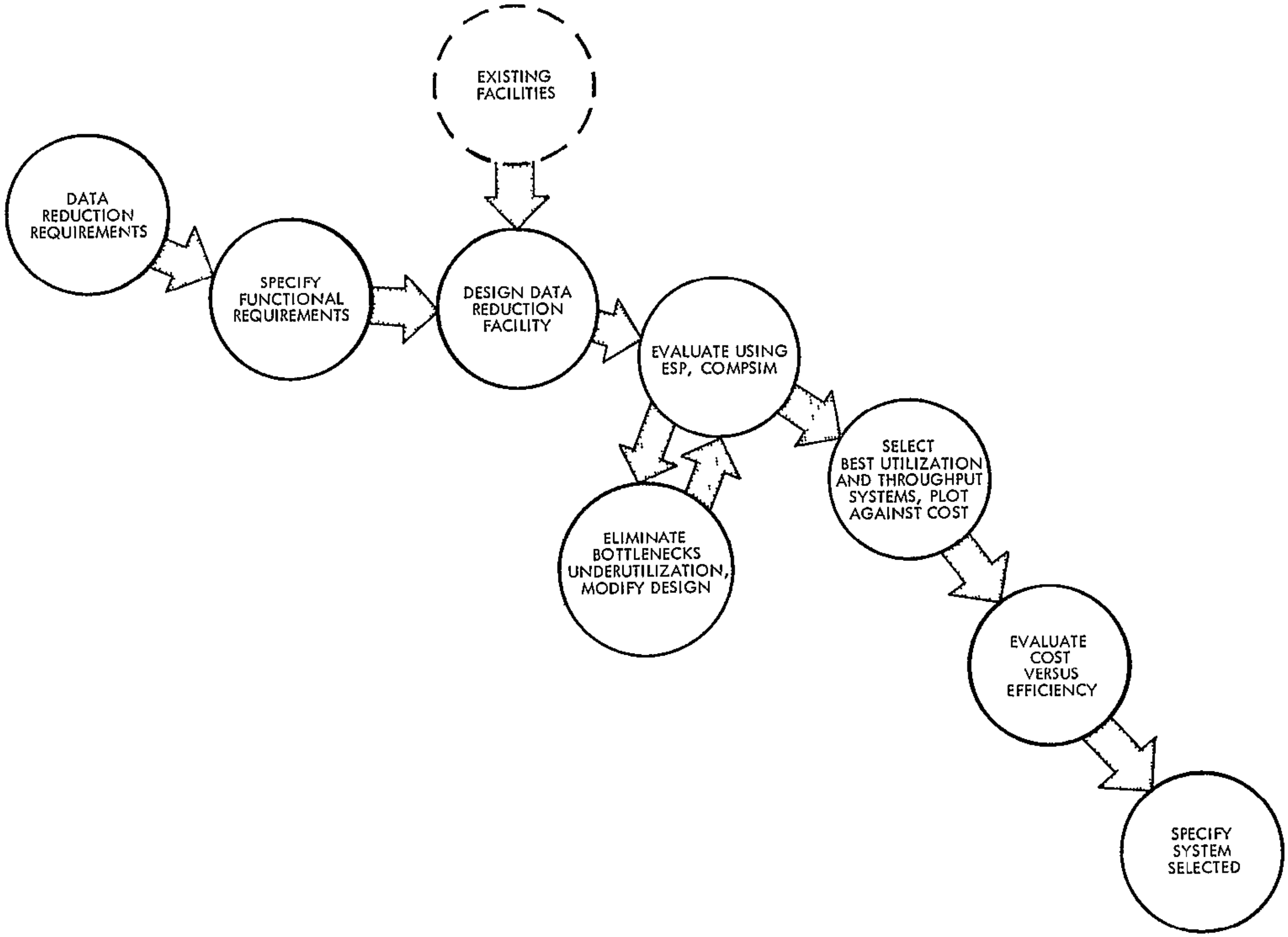

Figure 6-1. Simulation Approach

The CØMPSIM program simulates the detailed operation of a digital computer and maintains similar statistics regarding program, channel, device, and processor utilization

The system performance simulation programs use the TRW developed SALSIM discrete event simulation subroutine. This set of subroutines introduces a simulation capability to FØRTRAN. They also eliminate the need for a special language and provide for unlimited expansion of capabilities by addition of new subroutines, called functional operators, as the requirement arises. SALSIM also provides for a dynamic storage where storage is released when not further needed, allowing for use later in the simulation run. Expansion of the capabilities of simulation languages is typically difficult, but addition of extra subroutines to SALSIM is made relatively easy through the functional operators.

Using a functional operator found in SALSIM, a programmer writes FØRTRAN models of the equipment or process to be simulated These models provide for a flow of activities and simulate all time delays encountered Important statistics concerning the processing is maintained and printed at the end of a simulation run. These statistics show the throughput, percent utilization, unit queues, and other data vital to the analysis of a system's capability to process a given workload.

SALSIM is currently operational on the NASA/MSC 360/75, under RTOS and is used in the simulation programs described in the following two sections

6.3 The Equipment Simulation Program (ESP)

The Equipment Simulation Program was designed to simulate data processing systems which contain analog, digital and man-in-the-loop components. The program uses SALSIM to simulate the movement of data through the total system At the completion of a run, statistics provide for the evaluation of all pieces of equipment, or man intervention steps, in the complete data processing station. The program provides for input of photographic, analog or digital data, or a combination of any two or three and simulates the

processing of the data through devices selected by the user. Each device has a model (or subroutine) which defines the functions of that device. A set of parameter cards is provided to input key values relating to the computation of the device throughput.

6.4 The Computer Systems Simulation Program (CØMPSIM)

When the system designer addresses the problem of evaluating digital computers, the interactions of events become so complicated that the computer's capability and execution time to perform its given task are virtually impossible to determine manually. This is especially true when large scale, multiprocessor, multiprogrammable computers with complicated executive systems and multiple input/output channels, are under evaluation. To help the system designer evaluate the computers in the system, program CØMPSIM was developed. It provides detail software timing values for the computer functions in the ESP simulation.

There are three major components to any computer·

- Executive - the executive system is the master of the computer operation. It selects programs to be executed, answers interrupts from devices and routes input and output data to and from devices. It has total control over the internal operation of the machine, based upon the parameters provided it by the system or computer designer. These parameters consist of priority of programs, routing of input/output messages and interrupts.

- Programs - One of the primary purposes of CØMPSIM is to determine the total elapsed time required by a program to run to completion. Each program must be modeled, either by parameter cards or subroutine. A flow chart of the programs operation is used to determine the logical steps performed by the program, read, compute, write, branch based upon a probability of a computed value being within a given range, etc.

- Input/Output - Output devices may be computer storage devices such as disks or tapes or may be the next step in the data processing, such as CRT's or thematic plotters. Input devices also could be logical extensions of the computer or input channels from exterior devices such as digitizers. Exterior devices usually generate

interrupts to signal the computer that data is being sent through the channel. The executive must answer that interrupt and usually delays the executing program and schedules an input processor routine. One of the jobs that CØMPSIM performs is to determine how interrupts delay the execution of application programs thereby determining the actual elapsed time to completion of program.

These three components, along with the CPU('s) which actually perform the computation (the resource for which almost everything is competing) are simulated by CØMPSIM on a step by step basis Figure 6-2 shows the major computer components and their connection. The external system shown represents input devices which generate random interrupts (such as an interrupt from an operator console or CRT).

6.5 Equipment Models and Modular Functions

A sample application of the modular functions related to an equipment model is shown in Figures 6-3 and 6-4. The desired data product is a very simple photomap with limited thematic identification. The image data is available in the form of video signal on video tape. The modular functions necessary in this example application are:

- convert from video (analog) to digital signal (A-TØ-D)
- reference the data to an ephemeris (EPHEM)
- provide limited geometric correction of the data caused by the sensor optics (OPTGEØ), the sensor circuitry (SENGEØ), and the curvature of the earth (CURVAT)
- provide limited radiometric corrections due to the sensor circuitry (SENRAD)
- examination of the data by an operator (DISPLAY)
- manipulation for enhancement of the data through combination of data channels (SUBADD) and visual emphasis of certain data characteristics via thresholding (THRESH), i.e., ascribing a certain color to all data in a channel(s) above or below a certain value level
- once the data has been combined or displayed in a suitable fashion, photo prints thereof can be made (PRINTS)

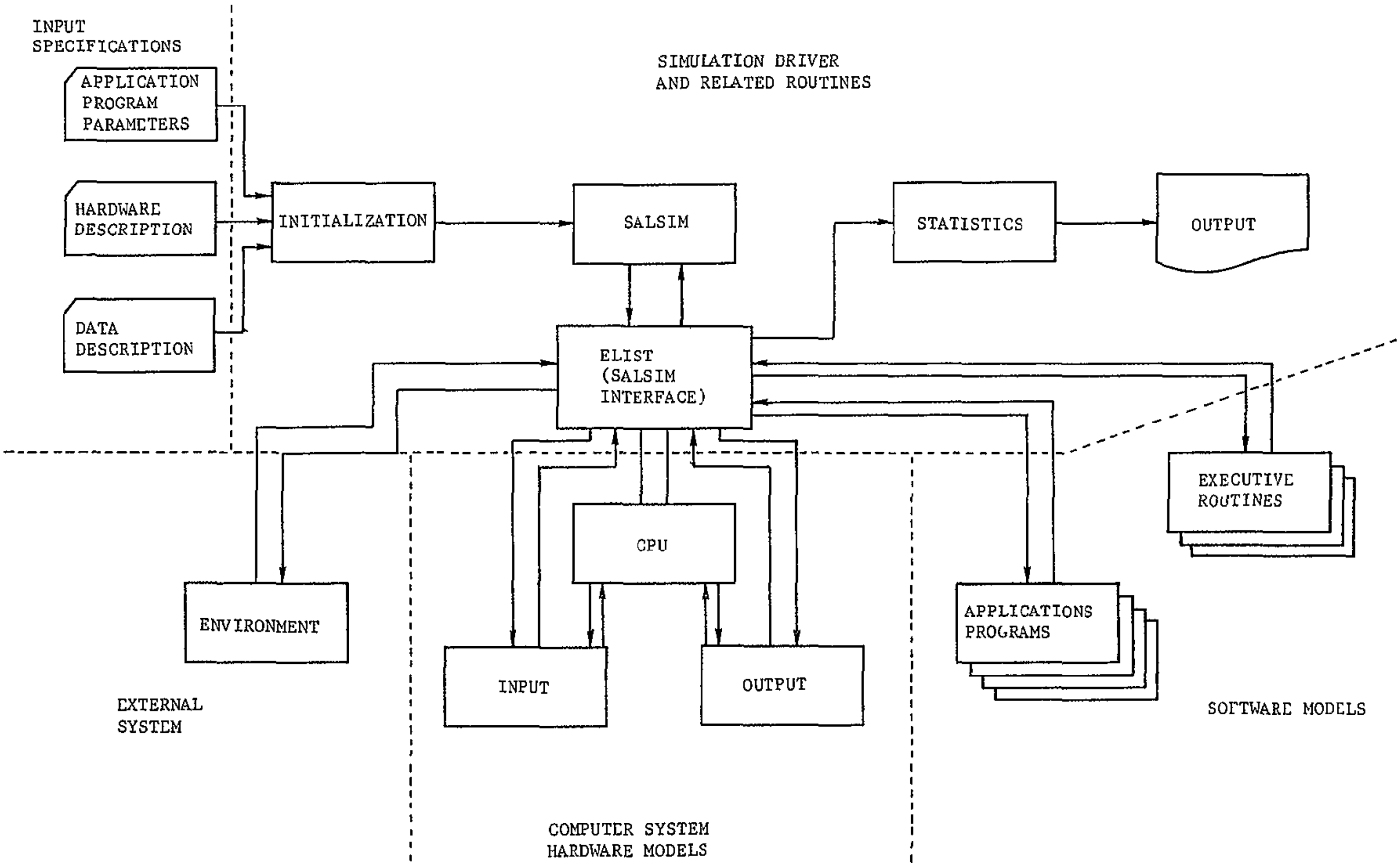

Figure 6-2. CØMPSIM Program Organization

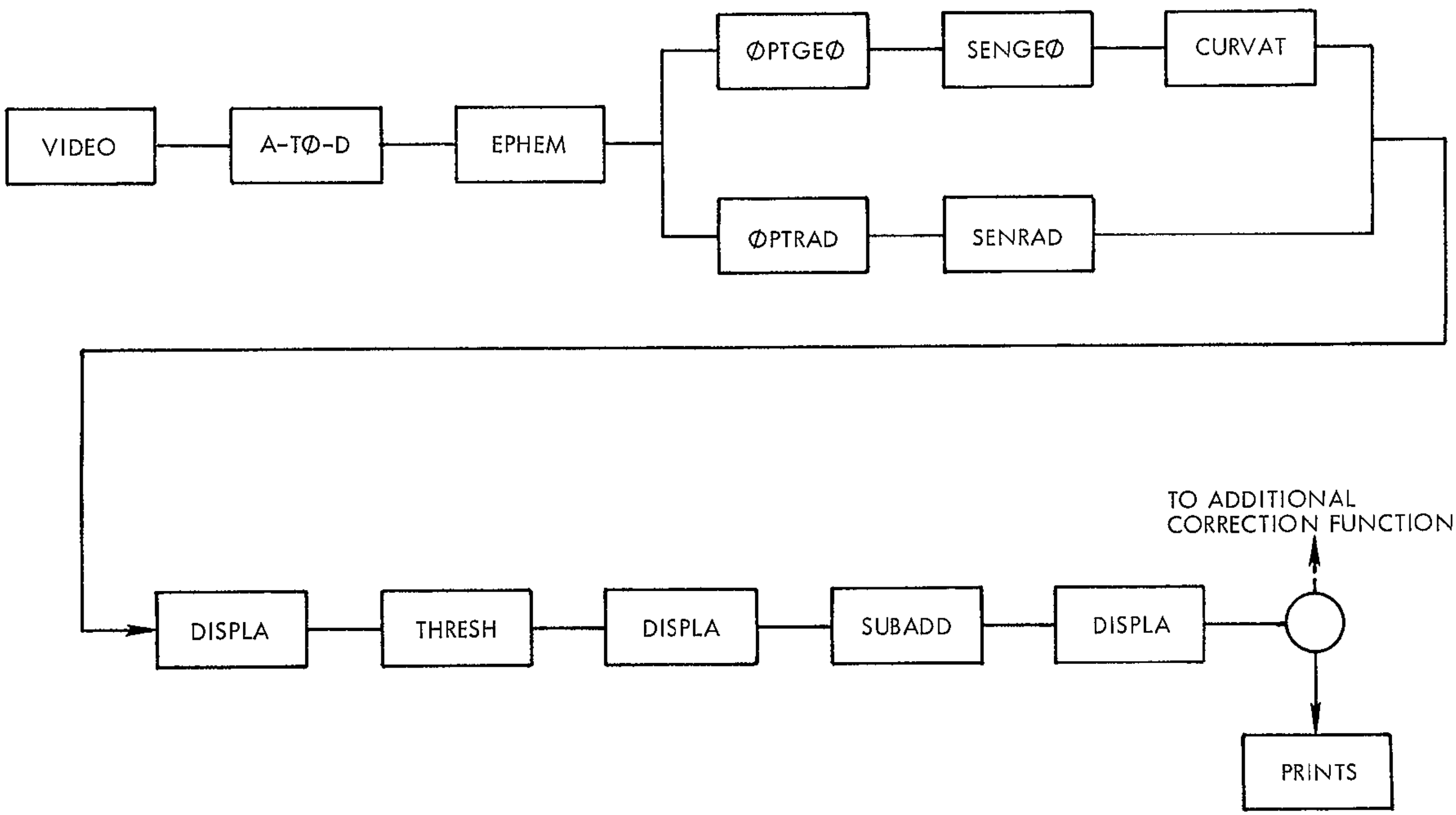

Figure 6-3. Functional Flow of Sample Subsystem

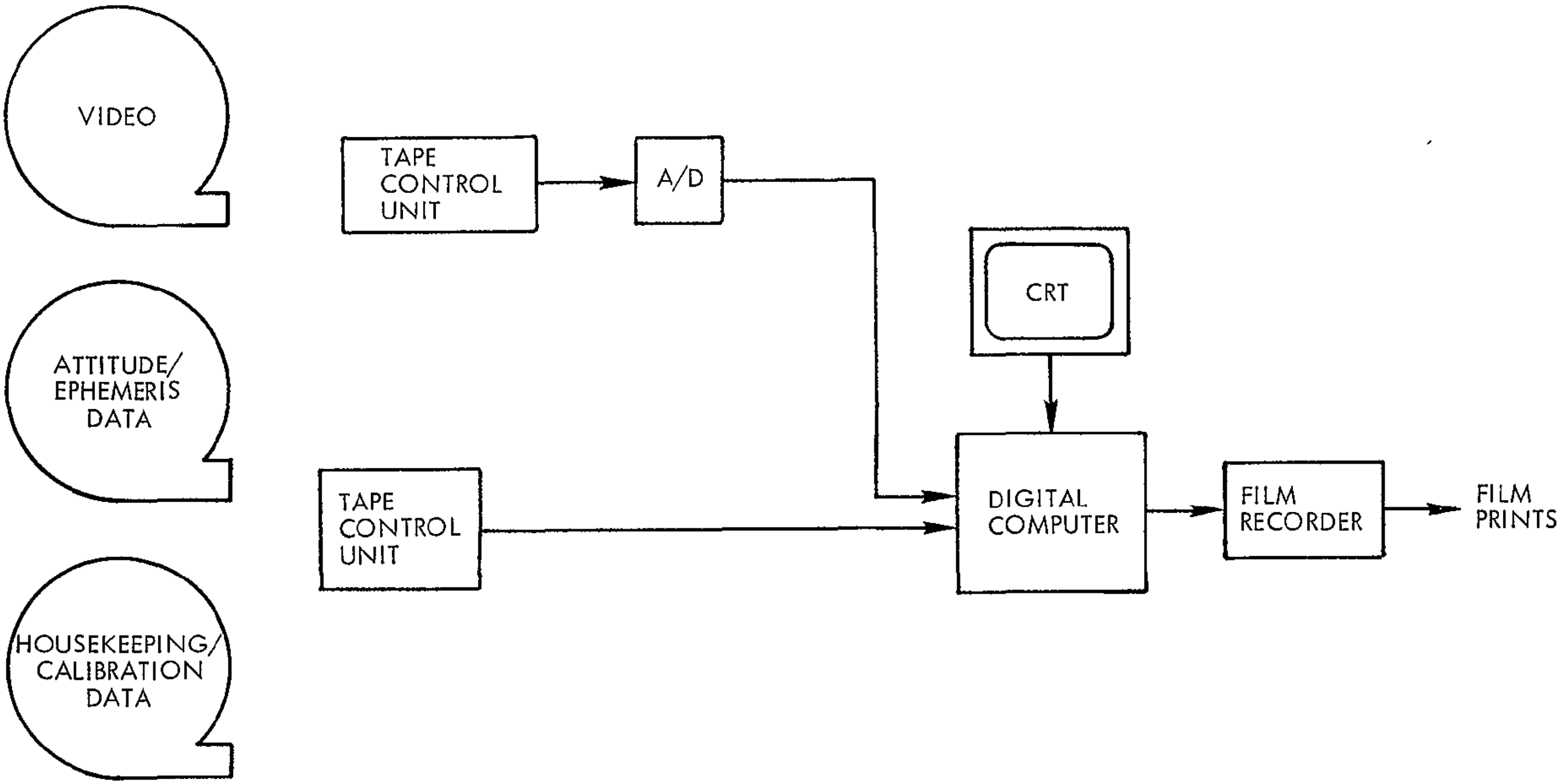

Figure 6-4. Sample Subsystem Schematic

The above set of modular functions might be typical for an application wherein fine resolution, close registration, and absolute geographic reference were unnecessary, e.g., theme extraction for a coastal region depicting large areas of marsh, sand and water where the observer may only be interested in the gross areal extent.

Selection of the equipment complement type necessary for modular function implementation can be made from Table 5-12, "Equipment/Modular Functions Matrix" and Figure 5-10, "The Master Equipment Device Schematic." Applying experience and judgement, the minimum equipment complement consists of

- a video tape playback (or recorder) and control unit to respond to computer control
- an analog to digital conversion unit to make the data compatible with the digital computer input
- a digital computer is required to provide for reading the ephemeris, geometric, and radiometric data from tape inputs. The computer subsequently performs the necessary calculations to effect the proper correction control signals to the film writer. These signals include the incremental x and y deflection values plus the z axis modulation values to be applied to each pixel as it is written
- a CRT and operator console equipment are required so that the operator may view the data and cause the channels to be manipulated to depict the enhancement or thematic content desired by the operator
- the film recorder equipment may be of the EBR (Electron Beam Recorder) type or the CRT type so long as the intensity of the beam and the deflection may be incrementally influenced by the digital computer output signals to effect geometric and radiometric corrections

The next step in evaluation of the sample application is identification of the equipment device parameters so that sizing and system operation may be analyzed and evaluated via the simulation tools available. Typical model parameters for the device types are shown below·

- Tape Drive

  Search Time
  Read Rate
  Start

- Display, CRT

  Turn On and Warm-up Time
  Access Time
  Scan Line Acceptance Rate
  Operator Observation Time, Mean, Spread
  Probability of Operator Request for Manipulation Routines;
    Subadd
    Threshold
  Display Command Delay Times

- Computer

  Number of Processors
  Core Memory Size
  Cycle Time
  Executive Overhead
  Parameters for each Program;
    Routine Process Time
    Other Devices Accessed
    Size of Record Accessed or Released
    Storage Seized or Released (New or Old)
  List of Programs;
    Digitizer Input and Storage Routine
    Ephemeris Read and Correction
    Optical Geometric Correction
    Sensor Geometric Correction
    Earth Curvature Correction
    Sensor Radiometric Correction
    Display Routine
    Image Channel Manipulation Routines
      (Add, Subtract, and Thresholding)

- Video Tape

  Start Time
  Search Time, Mean, Spread
  Number of Auxiliary Channels
  Time Internal/Line Scan
  Scan Line Interval
  Scan Lines/Image
  Stop Time

- A to D

  Stage Delay
  Sync Pulse Delay Times
  Bits/Scan Line
  Scan Line Interval

- Disk Storage

  Storage Capacity
  Storage Used/Released
  Access Time
  Line Rate

Once the above device parameters have been determined, it is possible to employ the simulation tools to determine system performance in terms of throughput, time delays and volume. Quantitative information will be desired relating to

- bulk memory size and speed
- core memory size and speed
- display and other peripheral operation while processing
- word sizes, interface breadths and transfer rates
- primary and secondary data structures

As the data and parameters evolve for the proposed system device implementation, three options are available:

- if the implementation is simple enough, there is no need for simulation since adequate calculations may be performed manually

- if the implementation is complex, then the simulation offers a good solution

- the system implementation program may be such as to require both manual and simulation methods of evaluation

In the above sample system, some example parameters for the system data source might be as follows

Video Tape

Start up time	50 sec.
Search time	0 sec., 7.5 min.
Aux channel	2, (timing, 1 audio)
Bandwidth	3.2 MHz
Scan line data interval	720 μsec
Scan line non-data interval	80 μsec
Scan lines/image	4125 lines
Frame data interval	3.3 seconds
Frame non-data interval	0.2 seconds
Total frame time	3.5 seconds

In the above example, probably the most significant parameter of the data source is the fact that a frame of data can be input in about 3.5 seconds. For an ERTS type image the equivalent is approximately 16 million pixels or about 100 megabits of information to be handled and processed. If data can be made available at that rate, the question arises, is it possible to process and extract the desired results and output at the same rate? Film writing output devices can be found which will write that size image with time ranging from about 12 minutes down to the required 3.5 seconds. This then permits a tradeoff in throughput rate vs. cost.

6.6 CØMPSIM Software Models

CØMPSIM provides two methods for implementing software models. In the first method, for executives and other complex programs, the model can be written in FØRTRAN. A set of subroutines, called software operators, is provided to perform the necessary simulation functions. The second method, for less detailed models, is to construct the model entirely from software operators on special input cards. The resulting program model is executed interpretively. A given simulation may contain both simple and complex program models, in any order, with no restrictions on referencing from one type to another.

6.6.1 Complex Program Models

Any software model that requires calculations to be performed with, or logical decisions to be based upon, system attributes from the simulation data base must be written in FØRTRAN. All such attributes are stored in the SALSIM dynamic array Any CØMPSIM software operators, most SALSIM operators, and all FØRTRAN statements are legal in constructing a complex program model.

A set of subroutines, called software operators, is used to simulate the effect of the executing software model on the simulated hardware. These operators are:

JUMP (PGM)	Jump to program specified by PGM. PGM may be either program ID or program number
JUMPR (IRET, PGM)	Set the return address (location of statement number IRET) in the event notice before jump to PGM
RETN	Go to return address previously stored in event notice
JUMPX (IDN)	Destroy current event notice and resume processing with IDN. Used for restarting delayed tasks by a scheduler routine.

PRØCES (IRET, INST, WGT)	Process for time equal to number of instructions (INST) x weighting factor (WGT, cycles per instruction) x CPU cycle time. If WGT = 0, a default value for each CPU is used. If INST = 0, WGT is assumed to be actual processing time in μs. After process, next statement is IRET.
ENABLE	Allow interrupts on current CPU.
DISABL	Lockout interrupts on current CPU
TRIGGR (LVL, PGM, TASK)	Cause an interrupt on current CPU with a priority of 10000×LVL+priority of PGM (0-999). If TASK = 0, a new event notice will be created. If TASK = current event notice, TRIGGER operates as combination TRIGGR and ENDINT This is useful when information contained in the current event notice must be passed on to another program at a different interrupt level.
TIMER (NTMR, LVL, DELT, PGM)	Cause a delayed interrupt on current CPU in DELT sec with priority = 10000×LVL+priority of PGM. If NTMR = 0, a new event notice will be created for each call to TIMER. If NTMR ≠ 0, and is less than the number of timers defined for the current CPU, a special event notice will be used, and its time of occurrence changed by each call to TIMER
WAIT (IRET, IDSCH, IDQ, IØWN)	Wait for I/O. Task is delayed until all messages specifying task delay have completed transmission. If IDSCH, IDQ, and IØWN are specified, the current event notice is placed in a special waiting queue and a new task starts with IDSCH. After all messages have completed, the event notice is moved to the queue specified by IDQ and IØWN where it is available for rescheduling If IDSCH = 0, the event notice does a large PRØCES until all I/O has completed.
IDLE	Idle current CPU if no outstanding interrupts.
ENDINT (IDSCH)	Ends interrupt processing. If no returns are present in event notice, control is passed to IDSCH, or if IDSCH = 0, CPU is idled.
READ (DEV, NCHAR, WTCNT)	Read a record from device DEV of length NCHAR. If processing must stop until completion of read WTCNT = 1, otherwise WTCNT = 0

WRITE (DEV, NCHAR, WTCNT)	Same as READ
SIØ (DEV)	Start an input or output operation on device DEV. Not necessary before a READ or WRITE.
CHACT (CHANNØ)	Activate data channel CHANNØ
CHDACT (HANNØ)	Deactivate data channel CHANNØ

6.6.2 Simple Program Models

Simple program models are input on parameter cards according to the format described under Software Operator Cards in Section 6.7. The following operators are available for use:

Operator	Parameters
PROCESS	TIME (ms)
WAIT	PGM
JUMPR	PGM, ARGS
RETN	None
JUMP	PGM, ARGS
ENDINT	PGM
ENABLE	None
DISABLE	None
IDLE	None
TRIGGR	PGM
TIMER	PGM
READ	DEV, NCHAR, WTCNT
WRITE	DEV, NCHAR, WTCNT

The following operators are unique only to simple software operators

Operator	Parameters	Description
BRANCH	INST, PROB	Instruction number, probability of looping
CALL	ROUTINE, ARGS	Routine name, arguments
LOOP	INS, CNT	Instruction number, number of loops to be performed

6 7 Input Data Structure

6.7 1 Equipment Simulation Program

ESP parameters consist of three types of cards, all in a fixed field format. They define the type of data, flow of data through equipment and equipment parameters.

Data Identification Cards - These three cards identify data as photographs, analog recorded, or digitally recorded. There must be one card for each type, even if there is no data of a given test type. The format is given in the table below·

COL	CONTENTS
10	I = image data (i.e., photograph) A = analog recorded data D = digitally recorded data
15-20	Total number of frames of this type of data to be processed
21-30	Time at which this data is to be introduced into the simulation
31-40	Number of data points per frame (if digital)
48-50	Number for first piece of equipment to process this data. (See data flow cards.)
57-60	The total number of pieces of equipment used in first processing step

Data Identification Cards

Data Flow Cards - These cards give the simulation the order in which frames of data flow through the various pieces of equipment. The format is given in the following table.

COL	CONTENTS
1-5	Card number All data flow cards are numbered 1-N. Each card represents an equipment station or a man-assisted function in the total processing system.
10	C = more than one previous station
13-16	The name of the device used by this step of the data reduction
26-30	Next step card number. Card number of the next equipment station
30-35 35-40 40-45	If there is more than one next station, these columns give the other stations card numbers
45-48	Normally blank. If this card represents the last step of the data reduction, this field contains an ENDØ or FINI

Data Flow Cards

Equipment Parameter Cards - These cards contain the required parameters for each device For example, the digitizing rate of an A-D converter, the probability of an on-line analyst rejecting a frame due to cloud cover, etc. The format is specified below.

COL	CONTENTS
3-6	The name of this piece of equipment (same as col. 13-16 of the data flow cards). The last card contains ENDØ in this field and all other fields are blank
17-20	Total number of pieces of equipment of this type
31-40 41-50 51-60 61-70	Parameters pertaining to operation of this piece of equipment. Parameters continue on the next card(s) in these fields (with col. 1-30 blank) until all required parameters are input

Equipment Parameter Cards

The parameters to be used in these cards are defined for all pieces of equipment as the model for that equipment is developed

6 7 2 CØMPSIM

There are four categories of CØMPSIM input cards: group header cards, standard attribute cards, user attribute cards, and software operator cards (for simple program models which do not require FØRTRAN for logic and computation). An input group consists of a group header card, a standard attribute card for each entity of the group, an end of data card (*EØD), and, optionally, a user attribute card for each entity. The order of input groups is not restricted nor is the order of standard attribute cards within the group. However, if user attributes are specified, the corresponding user attribute card must follow each standard attribute card. Any program models (using software operator cards) must immediately follow the PRØGRAMS input group. If there are no simple program models, the PRØGRAMS input group must be followed by two end of data cards. Also, the last input group must be followed by an additional end of data card.

Many input cards contain hollerith data as well as an input string of numbers. Therefore, the following notation will be used in all tables in this section.

- Location of data on card (LØC).

  ci-j means card columns i through j
  Pn means parameter number n of the input string
  P1(i) means parameter 1 of the input string which
  starts in column i

- Type of data (TYPE):

  A means alphanumeric
  I means integer (no decimal point)
  R means real (must have decimal point)

- Attribute names (ATTR NAME), where listed, are internal data names. If an attribute name is not given, the parameter is used only during initialization

All parameter input fields (denoted by Pn in LØC columns), even the final field in the string, must be terminated by a comma.

Group Header Cards - There are ten input groups in CØMPSIM. PRØGRAMS, FILES, CHANNELS, MULTIPLEXØRS*, CØNTRØLLERS, DISCS, DRUMS, TAPES, SEQ DEVICES, AND PRØCESSØRS. Each input group must begin with the appropriate Group Header card (see following tables). Only the first four four letters of the group name are required, the rest are optional.

Standard Attribute Cards - Each input group must contain a standard attribute card for each entity referenced in the simulation. A reference can come from a software model (a JUMP(N) operator requires that program N be defined), or from another input group (if file X specifies residence on drum Y, drum Y must be defined). The header card specifies the maximum number of entities in the system (for that group), and core is allocated for this number Entity numbering is from 1 to the maximum and unreferenced numbers do not have to be defined. Attribute cards do not have to be in sequence by entity number, and a second card with the same entity number will override the first description.

User Attribute Cards - If the group header card for an input group specifies user attributes ($1 \leq P2 \leq 10$), each standard attribute card must be followed by a user attribute card. All user attribute cards have the same format, a string of up to ten parameters starting in column one. The meaning of the parameters must be determined by the user. Each input group has an associated CØMMØN block which contains all of the attribute pointers (to locations within the SALSIM dynamic array) for that group. Pointers to user attributes will be stored in a size 10 array whose name ends in USER. For example, the pointer to the second user attributes of PRØGRAMS would be in PUSER(2).

Software Operator Cards - Simple program models can be defined by means of software operator cards. The operators that can be used in this fashion, and their associated parameters, are described in Section 6.7.

* Not in current version of CØMPSIM

GRØUP NAME	LØC	TYPE	ATTR NAME	DESCRIPTION
PRØGRAMS	C1-4	A		'PRØG'
	P1(13)	I	NPGM	Number of programs in system
	P2	I		Number of user parameters
	P3	I		Maximum number of software operator cards in a program model
	P4	I		Maximum storage requirement for a simple program model
FILES	C1-4	A		'FILE'
	P1(C13)	I	NFILES	Number of files in system
	P2	I		Number of user attributes
CHANNELS	C1-4	A		'CHAN'
	P1(13)	I	NCHAN	Number of files in system
	P2	I		Number of user attributes
CONTROLLERS	C1-4	A		'CØNT'
	P1(13)	I	NCØNT	Number of device controllers
	P2	I		Number of user attributes
DISCS	C1-4	A		'DISC'
	P1(13)	I	NDISC	Number of discs in system
	P2	I		Number of user attributes
DRUMS	C1-4	A		'DRUM'
	P1(13)	I	NDRUM	Number of drums in system
	P2	I		Number of user attributes
TAPES	C1-4	A		'TAPE'
	P1(13)	I	NTAPE	Number of tape drives
	P2	I		Number of user attributes
SEQ DEVICES	C1-4	A		'SEQb'
				Number of sequential devices
				Number of user attributes

Group Header Cards

GROUP NAME	LØC	TYPE	ATTR NAME	DESCRIPTION
PRØGRAMS	C1-4	A	PGM	'First four' char of pgm name
	C5-8	A	PGM2	Last four char of pgm name
	P1(10)	I		Program number
	P2	I	PGMPRI	Program priority
	P3	I	PTYPE	Program type (1 = exec, 2 = app)
FILES	P1(1)	I		File number
	P2	I	FTYPE	File type: 1 = random 2 = sequential
	P3	I	FADDR	Starting address of file
	P4	I	FSIZE	File size in granules
	P5	I	FREC	Record size in characters (sequential) or smallest accessed group of char. (random)
	P6	I	FDEV	Device (type and number) where file resides
	P7	I	FGRAN	Granule or block size in characters
CHANNELS	P1(1)	I		Channel number
	P2	I	CHTYP	3 digit channel description, a b c a = 0, interrupts do not deactivate chan = 1, interrupt deactivates until CHACT = 2, chan deactivated until int recognized by CPU b = 0, integral channel = 1, direct memory access c = 1, selector type channel = 2, RR multiplexor = 3, priority mux.(line 1 highest priority)
	P3	I	CHCPU	CPU to which channel is connected
	P4	R	CHRATE	Channel rate (char/sec)
	P5	R	CHSEL	Line selection time (ms)
	P6	I	CHIL	Interrupt level
	P7	R	CHINT	Channel interference for 1 transfer
	P8	I	CHNL	Number of lines
	P9	I	CHNC	Number of char transferred in parallel
	P10	I	CHIPGM	Interrupt answering pgm #1

Standard Attribute Cards

CØNTRØLLERS	P1(1)	I		Device controller number
	P2	I	DCLINK	Channel (2 digits) and line # (2 digits) of device cont
	P3	R	DCBUFR	Buffer rate if controller is buffered
	P4	I	DCNL	Number of lines for devices
DISCS	P1(1)	I		Disc number
	P2	I	DILINK	Link type (1 digit; 1 = channel 2 = device controller, 3 = mux.), number (2 digit), and line number (2 digit). (line 7 of device controller 3 = 20307)
	P3	R	DIACS	Access time in sec. If DIACS 0., a random access time, 0 t_{acs} t_{rot}, will be used If DIACS = 0, the access time will be computed using specified address and current angular position
	P4	R	DIRØT	Period of rotation in sec.
	P5	R		Interleave factor
	P6	I	DITKSZ	Track size (char)
	P7	I	DISEEK	Seek function number; must correspond to a user supplied function, SEEKFn, where 1 n 9.
	P8	R	DIAVSK	Average seek time in sec if no seek function is supplied
DRUMS	P1(1)	I		Drum number
	P2	I	DRLINK	See DILINK
	P3	R	DRACS	See DIACS
	P4	R	DRRØT	See DIRØT
	P5	I		Interleave factor
	P6	I	DRTKSZ	See DITKSZ
TAPES	P1(1)	I		Tape number
	P2	I	TPLINK	See DILINK
	P3	R	TPLAT	Start-up time (sec)
	P4	R	TPXFER	Data transfer rate (char/sec)

Standard Attribute Cards (Cont'd.)

SEQ DEVICES	P1(1)	I		Sequential device number
	P2	I	SQLAT	See DILINK
	P3	R	SQLAT	Device latency (sec)
	P4	R	SQIRTE	Input rate (char/sec)
	P5	R	SQØRTE	Output rate (char/sec)
PRØCESSØRS	P1(1)	I		CPU number
	P2	R	PCYTM	Cycle time (micro-sec)
	P3	I	PCC	Word size (char)
	P4	R	PRTM	Minimum channel interference to be considered
	P5	R	IWGT	Average number of cycles per instruction
	P6	I	NTMRS	Number of software accessible timers

Standard Attribute Cards (Cont'd.)

FORMAT	LOC	TYPE	DESCRIPTION
1	C1-5	I	Statement number (Do not use on PRØGRAM or END card)
	C7-14	A	Operator name
	P1(16)	I or R	First parameter
	P2-Pn	I or R	Remaining parameters (up to 20)
2	C1-5	I	Statement number
	C7-14	A	Operator name
	C16-23	A	First parameter
	P2(25) -Pn	I or R	Remaining parameters

Software Operator Card Formats

Format 1 is valid for all software operator cards. Format 2 is valid for operators which reference another program model. In this case, the first parameter may be either the program number (format 1) or the program name (format 2).

6.8 Output Information

6.8.1 Equipment Simulation Program

The general output of the Equipment Simulation Program consists of two lines of statistics for each type of equipment and each device as specified by the input parameter cards. Some models will print additional statistics relating to that device. The first line gives the equipment utilization for each equipment type. It contains

- Percent Utilization - the percent of the total simulation time during which the device is being used by a frame of data
- Total number of frames of data using the device
- The average time used by each frame
- A number identifying the user at the end of the run, if any
- The total number of interrupts which occurred, if the device is interruptable

The second line gives statistics regarding the wait queues at each device:

- The total number of frames which had to wait to be processed
- The total number of frames waiting to be processed at the end of the run
- The maximum number of frames waiting in the queue
- The average contents of the wait queue
- The average time per frame spent in the wait queue

The last two entries are standard SALSIM printouts and do not pertain to ESP. Table 6-1 shows an ESP run on a sample system and all of the output described above.

Table 6-1. ESP Output

EQUIPMENT UTILIZATION FOR TYPE LT

LT NUM	PERCENT UTILIZATION	NUMBER OF USES	AVERAGE TIME PER USE	CURRENT USER	NUMBER OF INTERRUPTS
1	94.07	13	1.817E 02	0	0
2	87.35	12	1.628E 02	0	0

LT QUEUE(S)

QUEUE NR	TOTAL ENTRIES	CURRENT CONTENTS	MAXIMUM CONTENTS	AVERAGE CONTENTS	AVERAGE TIME/MEMBER	ZERO ENTRIES	PERCENT ZEROS
1	11	0	9	3.67	0.838E 03	0	0.0
2	10	0	8	3.05	0.765E 03	0	0.0

EQUIPMENT UTILIZATION FOR TYPE SCAN

SCAN NUM	PERCENT UTILIZATION	NUMBER OF USES	AVERAGE TIME PER USE	CURRENT USER	NUMBER OF INTERRUPTS
1	15.05	21	1.800E 01	0	0

SCAN QUEUE(S)

QUEUE NR	TOTAL ENTRIES	CURRENT CONTENTS	MAXIMUM CONTENTS	AVERAGE CONTENTS	AVERAGE TIME/MEMBER	ZERO ENTRIES	PERCENT ZEROS
1	2	0	1	0.02	0.655E 01	0	0.0

EQUIPMENT UTILIZATION FOR TYPE CRT

CRT NUM	PERCENT UTILIZATION	NUMBER OF USES	AVERAGE TIME PER USE	CURRENT USER	NUMBER OF INTERRUPTS
1	74.01	32	5.808E 01	0	0
2	69.24	30	5.796E 01	0	0

CRT QUEUE(S)

QUEUE NR	TOTAL ENTRIES	CURRENT CONTENTS	MAXIMUM CONTENTS	AVERAGE CONTENTS	AVERAGE TIME/MEMBER	ZERO ENTRIES	PERCENT ZEROS
1	10	0	1	0.03	0.692E 01	0	0.0
2	11	0	1	0.07	0.166E 02	0	0.0

6 8 2 CØMPSIM

Three types of output are available from CØMPSIM Two of these, the operator trace and summary statistics, are built-in to the simulation. The third type, often the most important, is user generated output which is tailored to the specific problem under study. An example of each type of output is included in this section.

Operator Trace

The operator trace is designed to provide a detailed history of the software execution Selected operators (see table below) cause a line of output to be printed each time the operator is used. Operators are selected by setting bits in the program variable ITRACE. In addition to the software operators, a trace line can be obtained whenever a CPU interrupt occurs (CPUINT) and when a higher priority task takes over the CPU (DELTSK and NEWTSK). A trace line consists of the current simulation time, the operator name, the current task pointer, current CPU, the first four characters of the current program name, and the previous (calling) program name, the time the current program began execution, the interrupt priority, the remaining process time, the I/Ø wait count, and information on the associated message. The trace is useful for timing studies and also to insure that the software models are executing as expected An example of trace output is shown in Table 6-2.

TRACE SELECTION VALUES

Bit No.	Integer Value	Cumulative Value	Operators for Which Trace Activated
0	1	1	CPUINT, NEWTSK, DELTSK
1	2	3	JUMP, JUMPR, JUMPX, REIN, IDLE, ENDINT
2	4	7	TRIGGER, TIMER
3	8	15	ENABLE, DISABL
4	16	31	PRØCES, WAIT
5	32	63	SIØ, READ, WRITE
6	64	127	CHACT, CHDACT

Trace Operators

Table 6-2. CØMPSIM Trace Output

TIME	ØPERATØR	TASK	CPU	CPGM	RETN	MARK TIME	INTPRI	RTIME	UTCNT	MSG	ØRIG	DEST	CHAN	PRØT
1.908319	PRØCES	198	1	SUPE		1.908070	100000	.000000	0	366	1	0	1	0
1.910569	TRIGGR	198	1	SUPE		1.908070	100000	.000000	0	366	1	0	1	0
1.910569	ENDINT	198	1	SUPE		1.908070	100000	.000000	0	366	1	0	1	0
1.910569	CPUINT	416	1	INTP		1.910569	140201	.000000	0	0	0	0	0	0
1.910569	NEWTSK	416	1	INTP		1.910569	140201	.000000	0	0	0	0	0	0
1.910569	JUMPR	416	1	INTP		1.910569	140201	.000000	0	0	0	0	0	0
1.910569	PRØCES	416	1	RADI	INTP	1.910569	140201	.000000	1	0	0	0	0	0
1.910819	WAIT	416	1	RADI	INTP	1.910569	140201	.000000	1	0	0	0	0	0
1.910819	NEWTSK	341	1	EXTE		1.910819	140000	.000000	0	0	0	0	0	0
1.910819	PRØCES	341	1	EXTE		1.910819	140000	.000000	0	0	0	0	0	0
1.910889	TRIGGR	341	1	EXTE		1.910819	140000	.000000	0	0	0	0	0	0
1.910889	NEWTSK	341	1	SUPE		1.910889	100000	.000000	0	0	0	0	0	0
1.910889	PRØCES	341	1	SUPE		1.910889	100000	.000000	0	0	0	0	0	0
1.911139	ENDINT	341	1	SUPE		1.910889	100000	.000000	0	0	0	0	0	0
1.955850	CPUINT	291	1	RADI		1.955850	80101	.000000	0	173	1	0	1	0
1.955850	NEWTSK	291	1	RADI		1.955850	80101	.000000	0	173	1	0	1	0
1.955850	PRØCES	291	1	RADI		1.955850	80101	.000000	0	173	1	0	1	0
1.955999	TRIGGR	291	1	RADI		1.955850	80101	.000000	0	173	1	0	1	0
1.955999	NEWTSK	291	1	EXIØ		1.955999	120000	.000000	0	173	1	0	1	0
1.955999	PRØCES	291	1	EXIØ		1.955999	120000	.000000	0	173	1	0	1	0
1.956199	TRIGGR	291	1	EXIØ		1.955999	120000	.000000	0	173	1	0	1	0
1.956199	NEWTSK	291	1	SUPE		1.956199	100000	.000000	0	173	1	0	1	0
1.956199	PRØCES	291	1	SUPE		1.956199	100000	.000000	0	173	1	0	1	0
1.956449	TRIGGR	291	1	SUPE		1.956199	100000	.000000	0	173	1	0	1	0
1.956449	ENDINT	291	1	SUPE		1.956199	100000	.000000	0	173	1	0	1	0
1.956449	CPUINT	148	1	MWHP		1.956449	140209	.000000	0	0	0	0	0	0
1.956449	NEWTSK	148	1	MWHP		1.956449	140209	.000000	0	0	0	0	0	0
1.956449	JUMPR	148	1	MWHP		1.956449	140209	.000000	0	0	0	0	0	0
1.956449	PRØCES	148	1	RADI	MWHP	1.956449	140209	.000000	1	0	0	0	0	0
1.956698	WAIT	148	1	RADI	MWHP	1.956449	140209	.000000	1	0	0	0	0	0
1.956698	NEWTSK	341	1	EXTE		1.956698	140000	.000000	0	0	0	0	0	0
1.956698	PRØCES	341	1	EXTE		1.956698	140000	.000000	0	0	0	0	0	0
1.956768	TRIGGR	341	1	EXTE		1.956698	140000	.000000	0	0	0	0	0	0
1.956768	NEWTSK	341	1	SUPE		1.956768	100000	.000000	0	0	0	0	0	0
1.956768	PRØCES	341	1	SUPE		1.956768	100000	.000000	0	0	0	0	0	0
1.957018	ENDINT	341	1	SUPE		1.956768	100000	.000000	0	0	0	0	0	0
1.962415	CPUINT	291	1	RADI		1.962415	80101	.000000	0	316	1	0	1	0
1.962415	NEWTSK	291	1	RADI		1.962415	80101	.000000	0	316	1	0	1	0
1.962415	PRØCES	291	1	RADI		1.962415	80101	.000000	0	316	1	0	1	0
1.962564	TRIGGR	291	1	RADI		1.962415	80101	.000000	0	316	1	0	1	0

Summary Statistics

When several systems are to be compared or studied, statistics on the utilization of the various components are useful. Data for these utilization statistics are maintained by the software operators and by the hardware models. In general, there is a set of summary statistics corresponding to each input group described in Section 6 An example of the output statistics for PRØGRAMS is shown in Table 6-3.

Software Statistics. Total execution times are kept for each program model and also the number of times the program has executed (independent of the CPU on which it executes). Elapsed time is from the time the program starts until it executes a RETN, IDLE, or ENDINT operator. Processing time is maintained by the PRØCES operator. I/Ø delay is the time from the execution of a WAIT operator until the task is placed in the user specified scheduling queue. Interrupt delay is any time spent by the task in INTQ. Scheduling delay is time from the mark time stored in the task and the initiation of the task by means of a JUMPX or TRIGGER operator. The average values are obtained by dividing by number of executions

Hardware Statistics Each hardware group has certain associated utilization statistics. Processor utilization is given as percent of time idle, executing executive (PTYPE = 1) routines, and executing application (PTYPE = 2) programs. I/Ø channel utilization is given as percent of capacity as well as time for both burst and multiplex modes. The amount of data lost and individual line statistics are also given. Device controller utilization is split into percent of time transmitting data, waiting for interrupt service, and idle or control operations. The numbers of data transfer and control operations are also given. Device utilization percentages are for idle, control operation, access or latency, transmission, and interrupt servicing times. Total reads, writes, and control operations are given.

Table 6-3. CØMPSIM Program Output Statistics

PRØGRAM NAME	PRØGRAM NUMBER	NUMBER ØF EXECUTIØNS	AVERAGE EXECUTIØN TIMES IN MILLI-SECØNDS ELAPSED	PRØCESSING	I/Ø DELAY	SCHEDULING	INT DELAY
CPUPST	6	8	.500	.500	.000	628.099	.000
FALCHK	10	11	.198	.059	.000	.460	.000
FALSCN	12	3	8.335	7.999	.000	.892	.336
DACS	24	8	417.197	50.149	.000	2.569	.804
PBUPU	29	1	128.600	2.592	.000	.460	.000
SLDTIM	35	8	1.514	1.514	.000	154.884	.000
THIPRØ	37	1	202.374	1.530	.000	691.621	.000
TWØTEN	38	8	202.074	1.229	.000	98.310	.000
INTLØG	49	1	714.181	70.000	.000	71.484	1.398
ALCØNS	50	2	6.166	4.000	.000	170.806	.000
ALDISP	51	2	158.254	3.125	.000	87.049	.000
ALPRØC	52	1	460.108	4.897	.000	118.299	.000
CIP	54	2	1.157	.649	.000	164.709	.000
DEFSEL	63	1	.607	.099	.000	128.561	.000
PENT	69	2	1.788	.129	.000	293.567	.000
RETDIS	72	1	143.445	1.154	.000	61.299	.000
UPDATE	76	9	51.067	45.912	.000	178.402	.466
INTSPR	79	1	555.935	30.000	.000	112.819	.699
LLM	81	1	196.711	19.999	.000	28.633	.000
MWHLØG	82	1	910.375	80.000	.000	919.073	1.248
VM	83	1	140.782	9.999	.000	28.633	.000
DEHLØG	84	1	597.310	40.000	.000	174.657	.699
LØGØ	87	3	63.859	.999	.000	127.776	.000
DAØUT	89	9	766.262	.199	.000	199.373	.000
MWHPR	90	1	382.466	30.000	.000	253.190	.000
MWHSPR	91	1	353.155	30.000	.000	2432.566	.000
DLAPR	92	2	574.001	30.000	.000	793.469	.699
CPNA	110	6	131.141	.150	.000	26.935	.000
SCHEDQ	128	30	.761	.000	.000	.000	.000
WAITQ	129	55	.084	.000	.000	33.078	.000
TELQ	130	34	284.342	.250	.000	.000	.000
SLEEP	131	54	.206	.070	.000	179.849	.277
PERSCH	132	8	.017	.000	.000	.000	.000
PSEXIT	133	96	.000	.000	.000	.000	.000
RADIØ	134	402	16.467	.188	15.738	.595	.013
WAKEUP	136	54	.072	.000	.000	.000	.000
RUNREQ	137	60	.404	.047	.000	.000	.357
C3RUPT	1	28	.073	.000	.000	.000	.000
EXIØT	1[illegible]	247	.199	.199	.000	.000	.002
EXTENT	140	219	.088	.070	.000	.000	.018

User Outputs

When a particular computer system is to be analyzed in detail, the standard outputs are usually not sufficient, and outputs tailored to the specific problems must be generated by the user. This is a reasonably simple task in CØMPSIM since program models can be written in FØRTRAN and have access to the entire simulation data base. Table 6-4 shows an example of output generated by a model of an I/Ø handler routine The program occupying each overlay segment at the beginning and end of each RAD (Rapid Access Device) access is printed out along with the RAD user and the number of entries in the various executive scheduling queues

Table 6-4. CØMPSIM User Output

TIME	ACCESS	RAD	USER	SEG 1	SEG 2	SEG 3	SEG 4	SEG 5	SEG 6	SEG 7	SEG 8	SEG 9	SEG 10	NPRL	NRPL	NWTL
				(200)	(250)	(750)	(750)	(750)	(750)	(2000)	(0)	(0)	(0)			
3.323068	START	1	ALDISP	CPUPST		TWØTEN	TWØTEN		ALDISP	ALDISP				0	0	0
3.342254	STØP	1	ALDISP	CPUPST		TWØTEN	TWØTEN		ALDISP	ALDISP				0	0	0
3.342403	START	1	ALDISP	CPUPST		TWØTEN	TWØTEN		ALDISP	ALDISP				0	0	0
3.368150	STØP	1	ALDISP	CPUPST		TWØTEN	TWØTEN		ALDISP	ALDISP				0	0	0
4.000093	START	1	SUPER	CPUPST		SLDTIM	SLDTIM		ALDISP	ALDISP				0	1	0
4.041974	STØP	1	SUPER	CPUPST		SLDTIM	SLDTIM		ALDISP	ALDISP				0	0	0
4.287352	START	1	SUPER	DAØUT		SLDTIM	SLDTIM		ALDISP	ALDISP				0	0	0
4.309211	STØP	1	SUPER	DAØUT		SLDTIM	SLDTIM		ALDISP	ALDISP				1	0	0
4.309560	START	1	SUPER	DAØUT		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				0	1	0
4.403443	STØP	1	SUPER	DAØUT		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				0	0	0
5.078410	START	1	SUPER	DAØUT		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				1	0	0
5.121410	STØP	1	SUPER	DAØUT		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				1	0	0
5.121759	START	1	SUPER	CPUPST		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				0	1	0
5.143619	STØP	1	SUPER	CPUPST		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				0	0	0
6.000093	START	1	SUPER	CPUPST		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				0	1	0
6.041974	STØP	1	SUPER	CPUPST		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				0	0	0
6.287352	START	1	SUPER	DAØUT		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				0	0	0
6.309211	STØP	1	SUPER	DAØUT		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				0	0	0
7.104840	START	1	SUPER	DAØUT		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				1	0	0
7.147840	STØP	1	SUPER	DAØUT		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				1	0	0
7.148190	START	1	SUPER	CPUPST		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				0	1	0
7.170049	STØP	1	SUPER	CPUPST		TWØTEN	TWØTEN	UPDATE	UPDATE	UPDATE				0	0	0
8.000093	START	1	SUPER	CPUPST		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				0	1	0
8.041974	STØP	1	SUPER	CPUPST		SLDTIM	SLDTIM	UPDATE	UPDATE	UPDATE				4	0	0
8.042323	START	1	SUPER	CPUPST		SLDTIM	SLDTIM		INTLØG					3	1	0
8.070257	STØP	1	SUPER	CPUPST		SLDTIM	SLDTIM		INTLØG					3	0	0
8.070606	START	1	SUPER	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	1	0
8.102914	STØP	1	SUPER	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.103064	START	1	INTLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.122250	STØP	1	INTLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.122399	START	1	INTLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.150333	STØP	1	INTLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.150483	START	1	DEHLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	1	0
8.169669	STØP	1	DEHLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.169819	START	1	DEHLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.191192	STØP	1	DEHLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.191341	START	1	INTLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	1	0
8.210527	STØP	1	INTLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.210677	START	1	INTLØG	DEHLØG	DEHLØG	DEHLØG			INTLØG					2	0	0
8.2364	STØP	1	INTLØG	DEHLØG	DEHLØG	DEHL[illegible]			INTLØG					2	0	0
8.2365[illegible]	START	1	DEHLØG	DEHLØG	DEHLØG	DEHLØ[illegible]			INTLØG					2	1	0

7.0 CANDIDATE PROCESSING SYSTEM CONCEPT

An emerging concept for ground data processing is presented in this section. The concept is based on analysis and conclusions of study effort performed to date. Detail sizing and quantitative tradeoffs are yet to be performed to yield a refined system design. This iterative design work will be the subject of subsequent study activity and will depend heavily upon the System Performance Simulation developed in part under the current study.

7.1 Requirements Baseline

The intent in defining a candidate conceptual approach is to satisfy the following goals:

- provide a focal design activity for a ground processing system(s) which would become operational in the post-Skylab era (i.e., 1975) and have utility continuing well into the shuttle era and potentially be supportive of a space station (i.e., extending at least to 1985)
- establish a system design baseline which provides a departure point for subsequent detailed design and the inclusion of emerging requirements and technology
- provide a system concept that is predominately oriented to operational use of output products by user organizations

This latter goal has a significant impact on design assumptions concerning overall information distribution and the diversity of required data products (principally reducing the diversity from that required by a pure experimental program). Implicit in this goal is the additional assumption that operational utility can in fact be achieved early in the shuttle era It is the repeated contention and position of this study effort that this operational payoff can, and must, be realized in this time frame.

Given the above, the requirements baseline driving the system should be derived from the expected operational programs of the user agencies This is in sharp contrast to basing the system on an "experiments baseline"

such as the NASA "Bluebook" for Space Station. The analysis of user requirements performed within this study (fully reported in the Mid-Term Report and summarized in Section 3 0) provides the basis for the "Requirements Baseline" presented in Table 7-1 These requirements have been converted to an estimate of the raw input data volume necessary to drive the processing system. (Sections 7.4 and 7.5)

7.2 System Concept

The summary of requirements for data products and the estimate of input data volume support two contentions relevant to the selection of a candidate processing concept

First - the diversity of useful data products for the management programs considered is not great The number of uniquely different product types is less than twenty as opposed to several hundreds or thousands

Second - the overall input data volume required is only about 50 times greater than that now produced by the current ERTS A spacecraft covering the continental United States (digital data)

These two contentions stem from the recognition that while the diversity of analysis and interpretive functions performed by users may be great (i.e., the subjective and complex rationale that the user goes through in using various data products), the diversity of the actual data products or interpretive aids is not great. This intuitively follows from the fact that there is a relatively limited number of methods and media by which information may be communicated to a human analyst (this being particularly true if the predominance of the information is derived from a single source type e.g., imagery). Additionally, it is recognized that for remote sensing technology a great deal of the required products for various management functions are based on the same image scene(s), a fact which minimizes greatly the total amount of input imagery required to support multiple programs.

Table 7-1. Requirements Baseline

	WINTER	SPRING	SUMMER	FALL
PHOTOMAP	20	28	33	18
OVERLAY	76	98	103	66
THEMATIC MAP	51	130	75	45
SPATIAL MEASUREMENTS	27	42	30	21
SPECTRAL MEASUREMENTS	50	70	80	47
STATISTICAL SUMMARIES	13	34	35	9
AUTOMATED INVENTORY	40	56	47	30

AVERAGE UNIT PRODUCTION PER DAY FOR CONTINENTAL U.S. FOR SELECTED DATA PRODUCTS

In view of the above, the first and most fundamental characteristic of the recommended system concept is that the processing facility(ies) be somewhat self-contained and service oriented. It may make sense to have a number of geographically dispersed facilities (location based primarily on convenience and efficiency of interface with user agencies being serviced) but each facility is envisioned as being autonomous in its production of data products. The facilities are therefore "centralized" at least with respect to respective "regions" served, and go beyond just preprocessing of data to the production of a family of data products.

The centralized "service centers" would best be operated and managed by a single agency and would exist primarily to provide a service to the ultimate user and benefactor (e.g., U S.D.A , U S G.S., E.P A., NOAA, etc.). The individual user agencies would then either simply accept and consume the output data products without modification or subsequent processing, or in some cases they may require processing equipment within their facilities for subsequent specialized processing In this latter case, the intent would be to preserve compatibility between the processing systems of the service center and the agency facility, possible even to the extent of having compatible software systems and interchangability of hardware modules. This overall service concept is illustrated in Figure 7-1.

7.3 Processing Configuration

Within each service center a processing configuration would be implemented based on the work station approach illustrated in Figure 5-10. Two major exceptions to this schematic would be considered for any near term design activity; both the Optical Processing Station and Electronic Analog Station would be eliminated. These two processing alternatives are currently considered to be either too embryonic or too inflexible to be viable alternatives. This is a tentative design decision and one which should be reviewed as technology in these areas progresses.

The digital processing architecture of the central processing subsystem is currently envisioned as a single relatively large, general purpose uni-processor (e.g , 360/75 or 1108) which is heavily supported by special

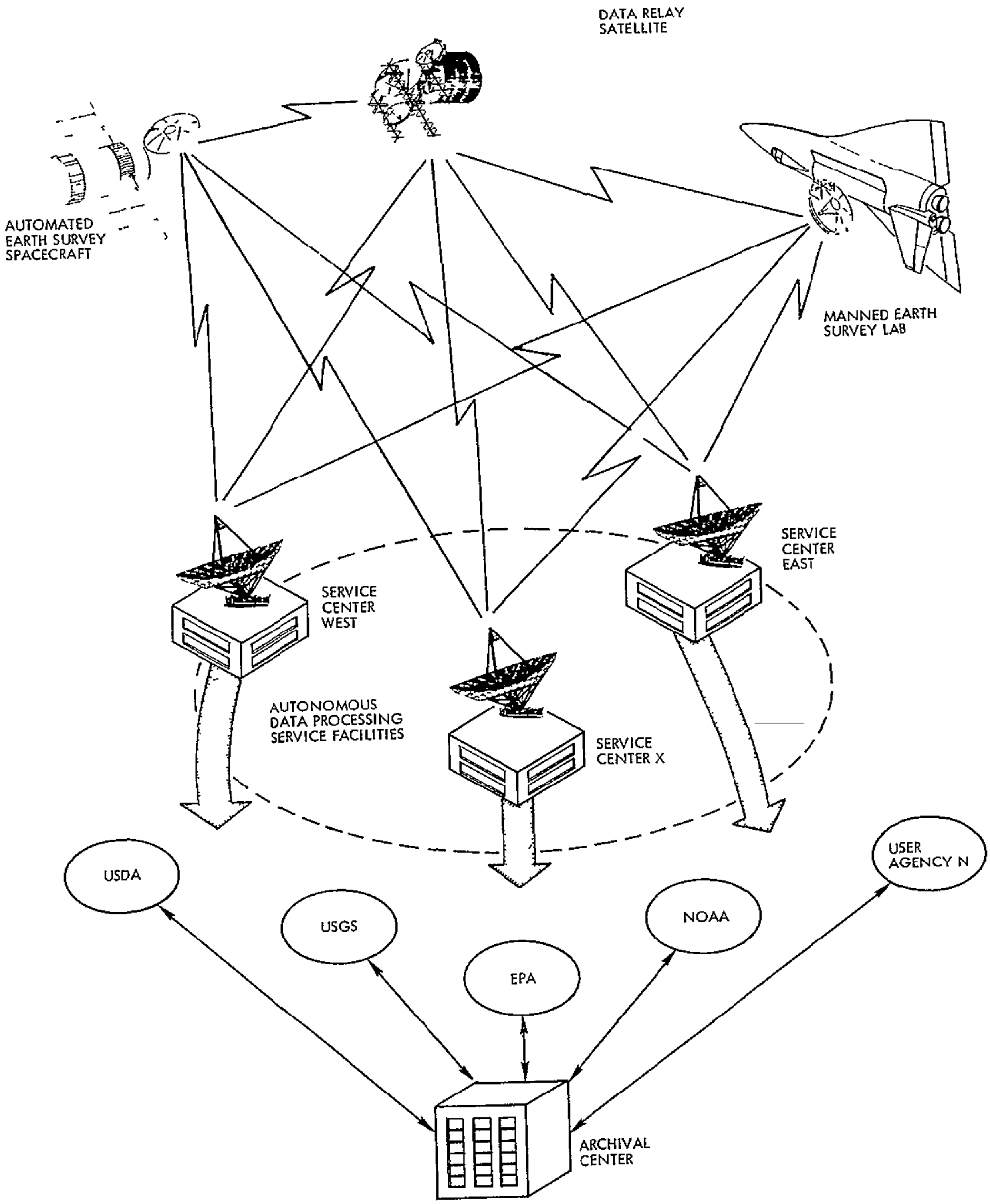

Figure 7-1. Service Processing Concept

purpose, solid state processing modules These modules are seen as performing most of the high throughput processing for the major functional categories of; preparation and conversion, correction and classification/recognition.

The sizing of the digital processors and the exact split between conventional software and specialized "hardwired" processing will be the subject of subsequent simulation studies

7.4 Data Storage and Distribution

Data storage for the baseline concept is viewed as accommodating primarily short term retention of data for correction and calibration purposes. An early estimate of the number of separate images flowing through the facility is approximately 1800/week (100 n. mi. by 100 n. mi. frames, U.S coverage once per week, 6 spectral channels). This number of images probably sets an upper limit on short term retention for "system tuning" purposes and is well within practical capacity of conventional digital or hard copy storage mechanisms.

Distribution of data products from the service center(s) to various user facilities is inherently no more demanding then the basic weekly data acquisition frequency. This would tend to indicate that conventional courier or mail service would be entirely satisfactory for timely dissemination. No operational requirements are seen for real time or electronic communication of data products from the servicing facility to the users.

7.5 Onboard Implications

The implications to onboard processing of the candidate concept are simply:

- minimize the acquisition of unacceptable data (excessive cloud cover, etc) and data not of interest, through adaptive collection techniques (either automated or man monitored, as in the case of the ERTS Operations Control Center at GSFC)

- perform onboard corrections and calibration that are based primarily on subsystem induced distortion or errors

- compress the data prior to direct transmission to the service center(s) on the ground

The baseline requirements (Table 7-1) convert to a total data acquisition rate of about 3.0×10^{11} bits/day (communication rate of 3.5×10^{6} bits/sec, 24-hour operation) which is well within the capability of current transmitting, receiving and recording technology, particularly if more than one satellite is used (e.g., the weekly coverage requirement most probably would be obtained with two phased "ERTS" type sun-synchronous, 500 n. mi platforms) and more than one receiving service center is envisioned, as illustrated in Figure 7-1.

7.6 Impact on Shuttle Missions

The advent of the shuttle would have two ramifications to the candidate concept; first, the shuttle as a launch and maintenance system for heavy automated payloads (i.e., about 7,000 lbs. into circular polar orbit at 500 n. mi.) would provide a significant payload increase over the 2,000 lb. ERTS class payload, this in turn providing for essentially a longer life payload and increased resolution through accommodating heavier optical systems, and second, the "manned lab" possibilities of an earth observatory could greatly facilitate the desirable adaptive data acquisition techniques mentioned earlier. This latter possibility of a dedicated manned laboratory for earth survey onboard the shuttle is the primary area in which refinement of the candidate concept could impact both shuttle payload design and mission management for these earth resources "service" missions (Note: the requirement for weekly frequency does not necessarily dictate continuous, uninterrupted coverage, and could conceivably be satisfied by 7 day sortie missions, end-to-end).

8.0 DATA PROCESSING ISSUES

As this study progressed, a number of items outside of the study scope presented themselves as highly important in developing a total picture of the requirements for processing remotely sensed data The purpose of this section is to present discussions of selected topics of this nature

8.1 Data Communications and Processing Distribution

The mode of transmitting data among various points and the distribution of processing functions are basic areas of concern in formulating system design concepts. Although such considerations were beyond the scope of this study, some general observations have resulted from analysis of processing requirements.

This study has established the fact that between the extremes of raw data and the results of analysis there is a definite set of data products which aid the analysis process. Furthermore, these products can be standardized to a great extent. Therefore, the scope of considerations of communications must include

- data acquisition (ground)
- development of interpretive aids
- analysis
- data archiving

This study has relegated analysis to the users of the system as well as the development of specialized data products. For example, an important tool in geological applications is the tectonic map; conceivably a useful map product could be provided to the geologist with the identification of tectonic features left to him, the tectonic map is an example of a specialized data product based upon a more general data product.

In the material which follows reference will be made to "centralization of functions" and "distribution of functions." Centralization should be taken to include possibly more than one center, i e., there may be several

centers, but each is capable of producing a total range of data products.

At least the following system concepts merit further consideration.

- Super - APT - This sytem would represent an extrapolation of the current Automatic Picture Transmission capabilities of meteorological satellites. Data would be transmitted directly (either in real time or later - dependent on available, cost effective band width) to users. The users would be responsible for generation of data products and analysis. The users could archive the data, send all data to a central repository or send only selected data to a central repository.

- ERTS/GDHS Derivative(s) - A central facility would be responsible for collecting raw data, performing corrections and providing imagery data to the user community The user community would generate all imagery based interpretive aids and perform analysis Archiving would be accomplished in a separate facility.

- Unified Center(s) - All functions related to generating standard data products would be co-located. The user community would be responsible for analysis Archiving would be performed in one facility.

- Unique Functional Center(s) - A collection of centers would be responsible for generation of standard data products with particular functions assigned to individual centers, i.e., one center might have responsibility for conversion and preparation, another corrections, etc.

All of these concepts must be examined from the viewpoints of economy and efficiency. As discussed in a later section, remote sensing will be competing with conventional data sources for a role in earth resources management, therefore, considerable emphasis must be given to assessing <u>total</u> costs of the system from reception of raw data to delivery of the final data product into the hands of the user. Furthermore, attention must be given to the interrelationships of the many functions associated with handling of remotely sensed data. Preliminary consideration of these problems has led to an initial bias in this study toward the Unified Center(s) concept As mentioned previously in this report, the initial goal was to identify the processing required, independent of where it was performed; as the analysis proceeded the unified concept demonstrated its viability.

8.2 On-Line Interaction

The purpose of this section is to provide some general observations concerning the continuing role of man in the analysis of remotely sensed data The discussion is presented in two parts

- the aspects of the technology in which limitations of automatic processes require manual intervention
- those aspects for which man is uniquely qualified

First, some background is necessary to set the stage for this discussion. The sophistication of man in analysis of imagery data must be considered in two phases First, man is capable of rapidly combining spectral, tonal, textural, and spatial data into inferences concerning the contents of the image based upon a knowledge of cultural and physical patterns. Second, augmented with mathematical tools and appropriate instruments, man can infer many additional facts concerning the imagery using standard photo-interpretive and photogrammetric techniques. Of the former group, the most promising area for automation to date has been spectral signature analysis.

Formidable problems confront attempts to automate even this one area. Within a given scene the spectral signature can vary significantly from field to field of the same crop due to changes in illumination, planting practices (orientation of rows, distance between rows, etc.), differences in available moisture, and other factors. These problems while significant considerations within a scene, become manifold between scenes of a different locale and a different time. An immediate consequence is that in some sense, the classifier must be "trained" to recognize spectral signatures within a limited region of time and space.

These difficulties have necessitated the use of ground truth. For clustering techniques the ground truth is used to assign points which "are close to each other spectrally" to categories. Other classification schemes make use of the statistical properties of elements of the imagery for which the category is known to classify the remaining points in the image. These methods can be combined by clustering and then classifying on the basis of class statistics.

Current classification systems make considerable use of man. Typical tasks of man are

- identification of truth sites within the imagery
- selection of training samples
- monitoring of classification

Identification of truth sites is highly important if precise knowledge of the sensor platform attitude and position is not known. In typical systems with a poor position/attitude base, the input data is clustered and an operator identifies truth sites using a map containing identification of fields.

Having located a truth site, it is necessary to select the sample spectral vectors which will be used to compute the classification statistics. This is typically performed by an operator using interactive displays. The operator may be required to monitor the effectiveness of the classification algorithm by noting its performance with respect to fields of known composition which were not in the training set.

All of the above discussion describes a somewhat straightforward process for agricultural fields which are basically "well behaved" i.e., essentially homogeneous. Wildlands present significantly more difficult problems, e.g., a statement that a region is forested with pine trees does not say that every resolution element will represent pine trees.

Most of the roles described for man for current classification activities could conceivably be automated with a certain degree of success assuming that the attitude/position base is well established - for "well behaved" cases. Beyond these cases it is highly unlikely that man's ability to identify using the many facets of data can be automated in the near future.

In addition to the role of man in classification, two other major areas, registration and measurement of control points, which currently make use of man are worthy of consideration. Defining registration simply as "aligning one image with another" the different processes involved must be considered.

Alignment consists of first recognizing like features in multiple images. Displacements among the features must be recognized and some satisfactory adjustment made. In theory, through optical or digital correlation techniques, the first two functions can be totally automated. However, in practice manual assistance through the use of interactive systems is a definite benefit to the process. Man can rapidly detect like features in interactive displays, select appropriate points for measurements through zoom capabilities and relegate the measurement function to the computer.

For control point measurements, once again, in theory, optical and digital correlation techniques can provide total automatic capability. Indeed, in the ERTS GDHS control point measurement is highly automated, but man performs a highly important role in selecting control points in the image which meet certain criteria As before, man is uniquely qualified for this role of noting immediately such conditions as the sharpness of the image in the regions of control points.

Man will continue to perform an important function in on line monitoring of automated processes. Certainly, this will not involve monitoring every step of processing on every pixel, but periodic checks in the development of data products will undoubtedly be a necessity. Once again in many cases a glance at an intermediate product can accomplish a multitude of functions related to image data product quality, any portion of which would present major problems to automate.

In addition to all of these, it must be recognized that photo interpretation is a highly developed science which requires many technical specialists. The very nature of many applications of remotely sensed data dictates that these specialists will be an important entity in any data processing center.

8.3 Data Archiving

The data archiving problem was not specifically addressed in the course of this study, but certain issues in this area are naturally introduced in consideration of processing requirements The purpose of this section is to summarize the observations of this study concerning archiving requirements.

First, a distinction must be made between short term storage and archiving. "Short term" as used here is that yet to be defined period of time in which data must be available to support operational analysis requirements. The bounding case of this category is data which must be available for change discrimination activities. Of the operational uses of remotely sensed data which were studied, a number which required change discrimination over a period of one week were identified. The interval over which changes are to be observed could extend to several years. For high frequency change discrimination activities, it would appear to be advisable to maintain files which are readily accessible. As the time interval between observations increases, the natural expectation is that penalties associated with restoration of data from archival media to readily accessible media would be tolerated.

Two alternatives for change discrimination support present themselves:

- First, the standard products of the processing center could be generated only on the basis of current data. Thus, the user agency would be responsible for the storage of past data (or data products) and the determination of changes.

- Second, a procedure could be instituted which would retain in short term storage that data required for change discrimination as specified in the agreement with the user agency.

Short term storage of certain data may also be required for calibration of instruments. Additionally, it should be anticipated that the processing of some imagery data may require corrective work after the data product has been examined by the user agency.

The archival requirements must consider the media, form and purging criteria for data. As indicated earlier, the media will probably be dictated by stability and physical compactness rather than rapid access. The form requirements are concerned primarily with the necessity of being able to precisely reconstitute original data. This latter consideration can be very involved as can be seen from the following example

- An obvious archival requirement might be to store the classification of ground cover. Thus, all the spectral data collected in a given bounded region could be stored as "grass." The storage requirement could be reduced from an extremely large number of observation vectors and associated ephemeris information to a simplified boundary description and the word "grass." However, if later applications require a comparison of the quality of the grass at five year intervals this simple descriptor is inadequate. Conceivably the storage of a sample mean vector and covariance matrix for the region would suffice for this problem.

Considerable engineering judgement would be required in assessing individual requirements for form of storage. The same level of complexity exists for determining purging requirements.

One of the strongest roles of remote sensing is the ability to identify synoptic changes to a region at selected intervals. Thus, a natural reluctance to ever lose data is introduced.

A possible, partial solution to the problems associated with archival form and purging is provided by a concept of tiered archiving, e.g., for a certain application it might be decided to retain raw data for one year, the classification statistics for that data for five years and an image of the region based on the data permanently - a three tier system.

All that has been introduced here are certain problems associated with archiving; much work remains to be done. It is highly important that analysis conducted in this area be concerned with all the ramifications of a variety of applications. Attention should be given to development of an archival system which is accommodative to individual needs.

8.4 System Flexibility and Growth

A major problem confronting the design of a system for handling remotely sensed data is that the precise functions to be performed by the system and the volume of input data and associated data products are unknown. The purpose of this section is to indicate the applicability of the forecasting techniques developed during the study to deriving a suitable solution to this problem manifested in system design which is responsive to changes in requirements.

First, it should be noted that if a limited role for the processing center is assumed, then accommodation to growth is rather straightforward. Given the functions to be performed the choice of equipments to handle changes in volumetric requirements gracefully is a standard design problem; albeit a very involved process. The primary difficulty is imposed when the range of processing functions is not specified.

In the Mid-Term Report the concept of acceptance modelling was introduced as a modulator to processing requirements Simply stated, the acceptance concept was an attempt to quantitatively describe the way in which a user agency would use remotely sensed data at various levels of availability of resolution, spectral range, automatic processing, swath and frequency of observations The concept provides a tool for addressing the problem of forecasting changes in processing requirements in the current condition of unknown data availability and use.

The manner in which processing trends are established is discussed in the Mid-Term Report. Continued refinement of the acceptance values in that report coupled with realistic assessments of evolving data collection systems would be very valuable in establishing trends against which requirements for current systems could be evaluated to prevent designs which emphasize certain facets of processing at the expense of others.

The primary danger which is evident in the user requirements analysis is a concentration upon automatic classification techniques without attention to more mundane roles of the system. This is a rather natural situation for the following reasons:

- Automatic classification techniques require a great amount of effort to produce economically acceptable algorithms (in terms of speed and accuracy)

- The U.S.D.A. is an agency pushing very hard to introduce remotely sensed data into its analysis chain, and many of the applications of this agency require automatic classification algorithms.

However, there are many uses of this new technology which require data products that are not dependent upon automatic classification. Many of these applications do require considerable attention to geometric and radiometric fidelity with large requirements for photographic and plotted data products. A primary goal with respect to system flexibility should be to identify those requirements which do not hinge upon technology risk areas (e.g , automatic classification and certain spectral range availability) and to assure that these applications can be accommodated by the ground processing system.

8.5 Econometric Considerations

The purpose of this section is to highlight the importance of econometric considerations in the total remote sensing program.

Three scenarios can be considered for the future remote sensing activities which have decidedly different econometric aspects The scenarios are.

- Experimental - Primary emphasis will continue to be upon development and refinement of remote sensing technology

- Discovery - Without any firm promise of return, early experiments in remote sensing show potential for dramatic breakthroughs in scientific knowledge or resource discoveries

- Operational - The technology is used to provide an additional or replacement data source to ongoing activities

An assumption throughout the following discussion is that the pressure of scrutiny of Federal funding will essentially preclude the first two scenarios as the dominant thrust of the Earth Resources Survey Programs. A successful program will need to push into operational applications. This particular scenario accommodates experimental and discovery functions, but the primary emphasis is upon support to critical earth resources management activities.

This immediately places remote sensing in competition with conventional data sources, with the pressure emanating from the fact that the new technology must <u>at least</u> provide the same information at a lower cost or a new capability at a marginally acceptable cost. An example developed by Ludwig Eisgruber at Purdue University helps to focus upon the criticality of these considerations.

A major activity of the U S D.A is the forecasting by the Statistical Reporting Service of various crops. Erroneous information on the expected size of a crop distorts optimal inventory carryover Eisgruber used an inventory adjustment model to compute the net loss in social benefit accruable to errors in forecasting yields of corn, soybeans and wheat. For these crops it is assumed that the forecast is made when production cannot be altered significantly in response to prediction about the quantity which will be available, but opportunities exist to adjust inventories and thus affect the price to be paid to the farmers. The following table summarizes the results of this analysis.

Estimates of Social Loss Due to Errors of Various
Magnitudes in Crop Estimates Corn, Soybeans and Wheat

Error of Estimate	Social Loss Resulting from Error of Estimate			
	Corn	Soybeans	Wheat	Total 3 Crops
(percent)	(million dollars)			
5	32.1	13 5	24 8	70 4
4	20 6	8.7	15 9	45 2
3	11 6	4.9	8.9	25.4
2	5 1	2.2	4.0	11.3
1	1.3	5	1.0	2.8

The net social benefit is computed by considering the true output, the forecasting error, the equilibrium price and the price elasticity of demand. The production base for these data was the average production and prices for the 1966-1970 time period.

Considering that for the foreseeable future remote sensing would probably have to show a major improvement in the cost associated with forecasting, or improve the accuracy, the next concern is the current level of competency. This figure is set at 2% error. Thus the margin of net loss in social benefit associated with halving the current error is $8.5 M The scrutiny of the new technology will focus upon the cost associated with an effort which incorporates remotely sensed data, versus current costs (not accounting for a natural inertia to change) relative to changes in such figures as the net loss in social benefits.

The considerations which enter such evaluations are summarized for the Agricultural Stabilization and Conservation Service compliance monitoring activities in Figure 8-1 Of prime importance relative to this study is the assessment of ground processing cost. Independent of decisions about distribution of processing functions, determination of the feasibility of remote sensing systems for a group of management functions must ultimately concentrate upon <u>total</u> ground processing costs, from receipt of raw data to delivery of a data product to the user.

IN COMPLIANCE	OUT OF COMPLIANCE	DETECTED	NOT DETECTED	CONSEQUENCE
X			X	IDEAL
X		X		$ EXPENDED NEEDLESSLY IN FIELD CHECK, GENERAL ANNOYANCE
	X	X		IDEAL
	X		X	$ WASTED IN SUBSIDIES AND OVERALL EFFECTIVENESS, GENERAL ENCOURAGEMENT FOR VIOLATORS

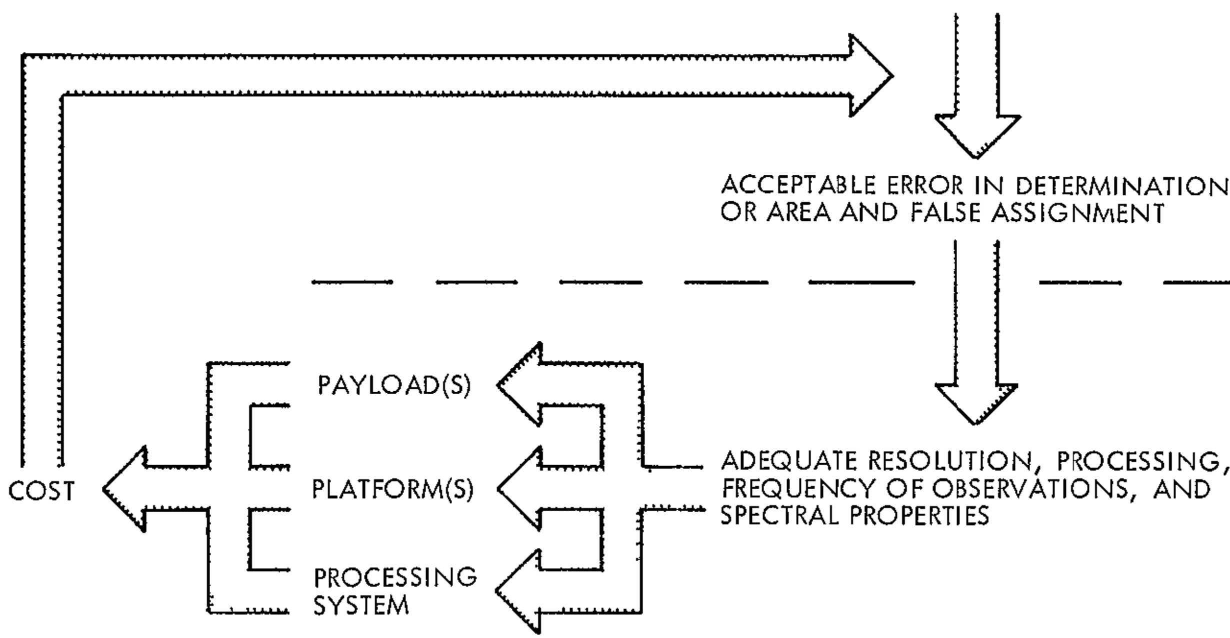

Figure 8-1 Compliance Monitoring Cost Considerations

@abs The author has identified the following significant results. Study emphasis was on developing a unified concept for the required ground system, capable of handling data from all viable acquisition platforms and sensor groupings envisaged as supporting operational earth survey programs. The platforms considered include both manned and unmanned spacecraft in near earth orbit, and continued use of low and high altitude aircraft. The sensor systems include both imaging and nonimaging devices, operated both passively and actively, from the ultraviolet to the microwave regions of the electromagnetic spectrum.